Factors affecting the transfer of science concepts by primary school students

By

Anne Pillman
BSc(Hons) *Adel,* MSc *Adel,* GradDipEd(Prim) *Hartley CAE,*
GradCertEd(Maths&Science) *UNISA,*
GradCertEd(Neuroscience) *Flin*

Thesis
Submitted to Flinders University
for the degree of

Doctor of Philosophy
College of Science and Engineering
14th September, 2022

Table of Contents

Contents

Table of Contents ii

List of Tables vi

List of Figures viii

Declaration x

Acknowledgements xi

Abstract xii

Prologue xv

1 Introduction 1

1.1 Transfer of learning and education 1

1.1.1 Transfer of learning and educating for a changing and less predictable future 1

1.1.2 Transfer of learning and educators' work 4

1.1.3 When transfer of learning fails 5

1.2 Transfer of learning and research 7

1.3 Connecting educators and researchers 9

1.4 Outline of this research 9

1.5 The impact of this research 12

1.6 Original contribution to knowledge 13

2 Literature Review 15

2.1 Overview 15

2.2 Definitions of transfer of learning 17

2.3 Taxonomies and classifications of transfer 20

2.3.1 Variation in the learning transferred. 21

2.3.2 Variation in the actions of the learners doing the transferring 24

2.3.3 Variation in the contexts of learning and transfer 26

2.4 Models and theories of transfer 28

2.5 Factors affecting transfer 32

2.6 Failure to transfer 37

2.6.1 Inert knowledge 37

2.6.2 Randomised controlled trials 38

2.6.3 Overzealous or negative transfer 39

2.6.4 Alternative perspectives on failure to transfer 39
2.7 A selection of transfer research findings 41
2.7.1 The radiation problem – a microcosm of transfer research 42
2.7.2 Transfer of physics concepts 46
2.7.3 Learning strategies 47
2.7.4 Learning programs 48
2.7.5 Mechanisms in transfer 49
2.7.6 Revisiting transfer 49
2.8 Transfer Research Methods 51
2.8.1 Analysis of individual student thinking 51
2.8.2 Big data analysis 52
2.8.3 Quasi experimental design 54
2.8.4 Translational research 55
2.9 Conclusion 57
3 Conceptualising transfer 58
3.1 Overview 58
3.2 Defining transfer 60
In the classroom 2 – definitions of transfer 61
3.3 Modelling transfer 62
In the classroom 3 – models of transfer 66
3.4 Factors affecting transfer of learning 66
3.4.1 Learning content 66
In the classroom 4 – describing learning content 68
3.4.2 The learning experience 69
In the classroom 5 – describing the learning experience 69
3.4.3 Learning and transfer tasks 69
In the classroom 6 – task components 71
In the classroom 7 – task degree of difficulty 74
3.4.4 How transfer is measured 75
In the classroom 8 – measuring transfer 77
3.4.5 Task environment 77
In the classroom 9 – task environment 78
3.5 Evidence of engagement 78
4 Current evidence of transfer in classrooms 80
4.1 Overview 80
4.2 Transfer in standardised testing 82

4.2.1 Introduction 82
4.2.2 Standardised tests used 82
4.2.3 Describing the learning 83
4.2.4 Transfer in NAP-SL 84
4.2.5 Transfer in TIMSS 91
4.2.6 Factors affecting transfer 95
4.2.7 Conclusion 98
4.3 Transfer in classroom tasks 99
4.3.1 Introduction 99
4.3.2 Method 99
4.3.3 Results 101
4.3.4 Discussion - Factors affecting transfer 114
4.3.5 Conclusion 116
4.4 Transfer in classroom tasks R-7 117
4.4.1 Introduction 117
4.4.2 Method 117
4.4.3 Results 119
4.4.4 Discussion 146
4.4.5 Conclusion 156
5 Experiments investigating the impact on transfer of a range of factors 160
5.1 Overview 160
5.2 Classroom strategies to support transfer – a pilot study 161
5.2.1 Introduction 161
5.2.2 Method 164
5.2.3 Results and discussion 170
5.3 Classroom strategies to support transfer – a field trial 182
5.3.1 Introduction 182
5.3.2 Method 184
5.3.3 Results – factors affecting transfer 194
5.3.4 Discussion 236
5.3.5 Experimental limitations 243
5.3.6 Conclusion 246
6 General Discussion 248
6.1 Implications for classroom teachers 248
6.1.1 Clarity around the intended learning and the situations in which transfer of the concepts is sought 249
6.1.2 Student learning dispositions and pedagogy 249

6.1.3 Feedback ... 250
6.2 Implications for educational administrators, policymakers, curriculum developers and assessment writers ... 251
6.3 Implications for students ... 253
6.4 Implications for educational researchers ... 254
6.4.1 Targeted and expanded perspectives on transfer ... 254
6.4.2 Disseminating/ communicating research findings ... 255
6.4.3 Challenges of translational research ... 255
Glossary ... 258
Bibliography ... 262
Appendices ... 287
Appendix A – School Materials for Differentiating Learning ... 287
Appendix B – A Range of Conceptions of Transfer of Learning ... 290
Appendix C – A Range of Classifications of Transfer of Learning ... 294
Appendix D – Examples of a Range of Models of Transfer of Learning ... 300
Appendix E – Common Methods in Transfer of Learning Research ... 303
Appendix F – Factors Affecting Transfer of Learning with Research Findings ... 305
Appendix G – Mapping Transfer of Learning ... 313
Appendix H – Ethics Approval for *Transfer in Classroom Tasks* Study ... 322
Appendix I – Australian Curriculum Chemical Sciences for classroom task ... 325
Appendix J – Student Record Sheets for Candle Task ... 327
Appendix K – Year 5 Student Responses to Candle Task Observation and Explanation ... 336
Appendix L – Year 5 Student Responses to *Explain with example* Task ... 338
Appendix M – Pilot Study Classroom Program ... 342
Appendix N – Ethics Approval for Pilot Study ... 343
Appendix O - Pilot Study ANOVA Results ... 346
Appendix P – Classroom Materials for Field Study ... 348
Appendix Q – Ethics Approval for Field Study ... 349
Appendix R – Field Study ANCOVA Results ... 352
Bibliography for Appendices ... 353

List of Tables

Table 2-1 Comparison of targeted and grounded definitions of transfer 19
Table 2-2 Coordination class framework 23
Table 2-3 Comparison of Depth of Knowledge and SOLO taxonomies of learning outcomes 26
Table 2-4 Dimensions of near and far contexts 27
Table 2-5 Research studies of transfer of science concepts years 4-8 32
Table 3-1 Task difficulty matrix 72
Table 3-2 Framework for mapping grounded transfer in student responses 76
Table 3-3 Framework for assessing engagement from feedback comments 79
Table 4-1 Curriculum details and Concept Outline of states of matter concept at year 5 level. 84
Table 4-2 Analysis of NAP-SL 2012 Question 21 using task framework 86
Table 4-3 Grounded transfer of concepts in Question 21 &22 88
Table 4-4 Analysis of NAP-SL 2012 Question 21 using task framework 89
Table 4-5 Task analysis and evidence of transfer in 4 TIMSS items 92
Table 4-6 Analysis of the Changes to a candle task using the task analysis framework 102
Table 4-7 Analysis of the statement explanation task using the task analysis framework 105
Table 4-8 Comparison of transfer in two classroom tasks (n=25). 108
Table 4-9 Distinguishing features of achievement levels in ACARA work samples 112
Table 4-10 Distribution of participants in classes 118
Table 4-11 Percentage of students transferring expected (blue) and targeted (red) learning. 120
Table 4-12 Level of transfer of science concepts in candle task. 121
Table 4-13 The degree of difficulty as measured in South Australian Primary schools 127
Table 4-14 Responses of reception students to the prompt to show how the candle changed when it burnt. .. 131
Table 4-15 responses of reception students after literacy coaching 132
Table 4-16 Response categories of Year 1 students to the candle task 133
Table 4-17 responses of Year 1 students to the generalised prompt 133
Table 4-18 Responses of Year 2 students to the candle task. 134
Table 4-19 Responses of Year 2 students to the generalised prompt. 135
Table 4-20 Responses of Year 3 students to the candle task 136
Table 4-21 Responses of Year 3 students to the generalised prompt. 136
Table 4-22 responses of Year 4 students to the candle task 137
Table 4-23 responses of Year 4 students to the generalised prompt 138
Table 4-24 Responses of Year 4 students to the further prompt 138
Table 4-25 Responses of Year 5 students to the candle task 139
Table 4-26 Responses of Year 5 students to the generalised prompt 140
Table 4-27 Responses of Year 5 students to the further prompt 140
Table 4-28 Responses of Year 6 students to the candle task 141
Table 4-29 Responses or Year 6 students to the generalised prompt 142
Table 4-30 Responses of Year 6 students in class b to the popcorn task 143
Table 4-31 Response of Year 7 students to the candle task 144
Table 4-32 Response of Year 7 students to the generalised prompt 145
Table 4-33 Misconceptions and limited conceptions shown by students R-8 in the candle task. 149
Table 4-34 Similarity in responses across classes 152
Table 5-1 Australian Curriculum: Science Chemical Sciences year 5 164
Table 5-2 Sequence of tasks in the Solids, liquids and Gases learning materials 165
Table 5-3 Distribution of variables for each of the 3 classes 166
Table 5-4 Coding of student responses based on SOLO 169

Table 5-5 Student response to the question of why learning might be important. 171
Table 5-6 Comparison of the percentage of students transferring the targeted science concept in the evaluation tasks 172
Table 5-7 Proportion of students using everyday causal nets across all tasks 175
Table 5-8 Trajectories of learners through the learning sequence. 177
Table 5-9 Percentage of student feedback about what they learnt 179
Table 5-10 Percentage of students who nominated these aspects of the learning as helping them learn 179
Table 5-11 Percentage of other feedback in each category 180
Table 5-12 Summary of participating schools, classes and students. 184
Table 5-13 Outline of units of learning 187
Table 5-14 Categories for describing evidence of transfer of the targeted concepts 191
Table 5-15 Framework for encoding student engagement from responses to the question: "Any feedback?" . 192
Table 5-16 Allocation of classes to experimental conditions. 193
Table 5-17 Effect of pedagogy on targeted transfer in Units 1 and 2 195
Table 5-18 Percentage of students demonstrating strategic and functional transfer in Unit 1 197
Table 5-19 Number (Percentage) of students with each of the nine possible combinations of pre and post-test strategic transfer in Unit 1 - low challenge pedagogy (n= 178). 199
Table 5-20 Percentage of students demonstrating targeted transfer for high and low challenge pedagogy in Unit 2 (n=169) 199
Table 5-21 Percentage of students with low challenge pedagogy demonstrating targeted transfer in pre and post-test for Units 1 and 2. 200
Table 5-22 A classification of task factors relating to increasing difficulty of transfer. 202
Table 5-23 Analysis of task difficulty in Unit 1. 203
Table 5-24 Analysis of task difficulty in Unit 2. 206
Table 5-25 Effect of absence from class and pedagogy on targetedn transfer in unit 2 209
Table 5-26 Variation between classes, schools and teachers in the Unit 1 post-test targeted transfer. 210
Table 5-27 Targeted transfer and teacher responses to class culture survey. 212
Table 5-28 Distribution of students in high, mid-range and low groups for each CLARA disposition (n=131) ... 215
Table 5-29 Percentage of students with high and medium CLARA levels demonstrating targeted transfer and improvement in transfer in Unit 1. 216
Table 5-30 Percentage of students improving targeted transfer for each CLARA score and pedagogy in Unit 2 218
Table 5-31 Effect of CLARA Orientation to learning score on improvement in targeted transfer 219
Table 5-32 Percentage of students giving feedback in each engagement category. 221
Table 5-33 Accuracy of student self-assessment in pre-test and post-test of unit 2 224
Table 5-34 Percentage of students showing improved transfer in Unit 2 post-test for responses to the Learning Science items. 226
Table 5-35 Key phases of the sequence of learning activities. 228
Table 5-36 Percentages of students demonstrating each possible learning trajectories. 230
Table 5-37 Summary of the findings from the field trial data set. 235

List of Figures

Figure 2-1 Duncker's radiation problem (Duncker, 1945, pp. 1-2) 42
Figure 3-1 Into the classroom - the classroom example 59
Figure 3-2 Into the classroom 2 - definitions of transfer 61
Figure 3-3 Two-step model of transfer 62
Figure 3-4 Some factors affecting transfer of learning. 63
Figure 3-5 Generalisation model of transfer 64
Figure 3-6 Into the classroom3 - models of transfer 66
Figure 3-7 Into the classroom 4 - describing learning content 68
Figure 3-8 Into the classroom 5 - describing the learning experience 69
Figure 3-9 Into the classroom 7 - task components 71
Figure 3-10 Into the classroom 7 - task degree of difficulty 74
Figure 3-11 Into the classroom 8 - measuring transfer 77
Figure 3-12 Into the classroom 10 - task environment 78
Figure 4-1 States of matter questions from NAP-SL 2012. 85
Figure 4-2 Some factors affecting transfer of learning 95
Figure 4-3 Work sample from ACARA Australian Curriculum satisfactory portfolio 110
Figure 4-4 Percentage of students transferring expected and targeted learning 120
Figure 4-5 Transfer of curriculum concepts by Reception level students 123
Figure 4-6 Transfer of curriculum concepts by Year 1 students 123
Figure 4-7 Transfer of curriculum concepts by Year 2 students 123
Figure 4-8 Transfer of curriculum concepts by Year 3 students 123
Figure 4-9 Transfer of curriculum concepts by Year 4 students 124
Figure 4-10 Transfer of curriculum concepts by Year 5 students 124
Figure 4-11 Transfer of curriculum concepts by Year 6 students 124
Figure 4-12 Transfer of curriculum concepts by Year 7 students 124
Figure 5-1 Initial student framing of the intended learning 171
Figure 5-2 Student framing of learning in Class A .... ***Error! Bookmark not defined.***
Figure 5-3 Final student framing of the intended learning 171
Figure 5-4 Percentage of students transferring the targeted concept for each task 173
Figure 5-5 Everyday causal net across all tasks 176
Figure 5-6 Factors affecting transfer of learning 182
Figure 5-7 Dimensions of learning power from (Deakin Crick et al., 2015) 189
Figure 5-8 Effect of pedagogy on targeted transfer in units 1 and 2. 195
Figure 5-9 Frequency of each level of transfer in Unit 1 low challenge pedagogy classes 198
Figure 5-10 Control group transfer of targeted concept across all tasks in units 1 and 2. 205
Figure 5-11 Percentage of students transferring across all tasks for low and high challenge pedagogy. 206
Figure 5-12 Effect of absence from class on targeted transfer in Unit 1 (all low challenge pedagogy) n=190 .. 208
Figure 5-13 Effect of absence on targeted transfer in Unit 2 for low (AA) and high (AB) challenge pedagogy. n=182 209
Figure 5-14 Targeted transfer in Unit 1 for mid and high CLARA disposition scores. 217
Figure 5-15 Improvement in targeted in Unit 1 for mid and high CLARA disposition scores. 217
Figure 5-16 Effect of the combination of CLARA dispositions and pedagogy on improvement in targeted transfer 218
Figure 5-17 Effect of CLARA Orientation to Learning score on improvement in targeted transfer 219
Figure 5-18 Percentage of students with improvement in targeted transfer for each engagement category. .. 222

Figure 5-19 Percentage of students with NO improvement in targeted transfer for each engagement category. 222
Figure 5-20 Percentage of students showing improvement in transfer for each engagement category. 223
Figure 5-21 Accuracy of self-assessment in Unit 2 pre-test (n=182) 225
Figure 5-22 Accuracy of self-assessment in Unit 2 post-test. (n=158) 225
Figure 5-23 Percentage of students showing improvement in targeted transfer for tell and practice preferences 227
Figure 5-24 Percentage of students showing improvement in targeted transfer for productive struggle preferences 227
Figure 5-25 Frequency of transfer of the targeted science concept at key phases in Unit 2. 229
Figure 5-26 Unit 2 learning trajectories for two classes 233
Figure 5-27 Expanded framework for factors affecting transfer 237
Figure 6-1 Transfer for learners – a set of questions for students to promote self-efficacy with transfer. 253

Declaration

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed

Anne Pillman

Date 22/2/2022

Acknowledgements

I wish to thank many people whose support has made this thesis possible.

To my supervisors, thank you for the time, energy and expertise that you have put into engaging with an “unconventional” thesis. Your different perspectives have challenged my thinking and enhanced this thesis in many ways.

To Martin, thank you firstly for being prepared to take a gamble on a student who did not fit with the age, recent experience or academic expertise norms of higher degree students. Thank you also for your unique blend of challenging my thinking while being positive about the long term potential of the project, for the time you put into meetings, especially when this was no longer your job, and for coming up with ways forward when this seemed impossible to me.

To Karen, thank you for reminding me of the constraints of higher degrees when I went off on tangents; and for your feedback on a thesis outside your area of familiarity.

To Shane, thank you for your detailed feedback on the drafts, your always prompt responses to my questions, and for being the last supervisor standing on many occasions.

To Lindsey, thank you for your interest in the project, for driving its progress in the early writing stage and for your belief that the work could be finished.

To Dr David Jeffries, thank you for taking on the statistical analyses for the pilot study and field trial and for answering my questions about choosing tests and interpreting data.

To the countless students and teachers I have worked with over the last thirty years, thank you for the opportunity to learn from your experiences of teaching and learning. Particular thanks to the teachers in the research projects for the time and energy you put into rearranging teaching programs, collecting forms and work samples and teaching with unfamiliar materials, especially those who had to teach the same material using two different pedagogies. Thanks also to the 320 students who participated in the research projects and had to do way more writing than they would have preferred. Your efforts have made this possible, and you and those who come after you are the reason for this research.

To my family and friends who have weathered nearly a decade of my commitment to this work, thank you for your patience and support. During this time, there has been one marriage, five births, two deaths, three serious illnesses and three house moves (including one from overseas). Thank you for asking how things are going (and listening to the responses), for putting up with my absences when I should have been around, and working around my less than optimal participation in everything from school drop-offs to concert preparation to social gatherings. Hopefully, things will be different now.

Abstract

The purpose of this research into the factors affecting transfer of learning was to identify for educators strategies that might optimise their students' capacity to transfer what they have been taught. The context chosen was the transfer of science concepts by students in Years 5 to 7, the final years of primary school in South Australia. The initial research question was: What factors affect transfer of science concepts by South Australian primary school students?

A review of cognitive science research literature on transfer of learning revealed a diverse range of perspectives and inconclusive research findings that were considered for their relevance to the context involving science concepts and upper primary level students. There is also a large body of research literature related to the affective domain was not included in the literature review. While some studies used primary aged students (5 to 12 years old), very few investigated these factors in primary school classroom settings and virtually none in South Australia. This study set out to address this gap by investigating transfer of science concepts in regular classroom settings. Informed by the research findings, frameworks were developed to describe the components of the transfer process and the variability within the factors affecting this process. These frameworks allow teachers and researchers to distinguish two different kinds of transfer, outline the targeted concept, describe the degree of challenge in a task and assess evidence of transfer in student work samples. All of these have been used in classrooms in addition to those involved in the study.

Five separate investigations were carried out. Initial qualitative studies sought evidence of transfer of science concepts from existing artefacts, including standardised test responses (Chapter 4.2) and classroom tasks (Chapters 4.3 and 4.4). These investigations identified a range of factors relating to the targeted concept, the transfer task and how transfer was measured as potentially affecting what students transferred. The investigation described in Chapter 4.4 broadened the group of students to consider how transfer of science curriculum concepts changed throughout the eight years of primary school.

The three studies above yielded no information about factors related to the learning experience or the students themselves. To address this gap, two experiments were carried out. These required the development of classroom materials that met the students' normal science program requirements, incorporated different learning conditions or pedagogy, and controlled for other variables such as time on task and task context. Two key differences in the pedagogy experienced by each class were productive struggle versus tell and practice methodology and expansive framing versus bounded framing. With productive struggle, Richland, Stigler and Holyoak (2012, p. 2) students engaged with a

task before being shown how the science concept could be used, whereas tell and practice students had the concept explained before they practised applying it in the same task. Expansive framing (Engle, Lam, Meyer, & Nix, 2012) refers to the way the concept is linked to students experience of the world outside of the classroom, as distinct from bounded framing which makes no reference to the learning of the concept outside the current classroom unit of work. The research question addressed in these studies moved beyond the description of factors in response to the initial question to describing the impact these factors on the transfer of science concepts. The question describing these studies was: How do factors relating to the students themselves, the concepts, the way these concepts were taught, the way transfer is measured together affect transfer of learning. The pilot study (Chapter 5.2) tested these materials using three classes (n=76) taught science by the same teacher. At the end of the unit, there was no difference in students' transfer of chemical science concepts related to gases between the three pedagogy conditions, but after four weeks, there was a small but non-significant difference in favour of the class who had productive struggle pedagogy. After a further ten weeks, the difference between the classes with and without productive struggle class was significant ($p<0.05$), suggesting that productive struggle pays dividends in far transfer. Near and far transfer in this study are distinguished by their distance from the time of learning, along the dimensions described by Barnett and Ceci (2002).

The field study (Chapter 5.3) involved a larger student cohort (n=244). In addition to measuring transfer of the targeted concepts about tectonic plates and electrical energy flow, several additional factors relating to students themselves such as prior knowledge, learning dispositions and preferences and absences from class, were measured. These included a measure of student learning dispositions using the Crick Learning for Resilient Agency (CLARA) tool (Deakin Crick, Huang, Ahmed Shafi, & Goldspink, 2015). CLARA uses an online survey tool to provide a score for each of 8 student learning dispositions: mindful agency, sense-making, creativity, curiosity, belonging, collaboration, hope and optimism and orientation to learning. For the classes with high challenge pedagogy (incorporating productive struggle and expansive framing), there was a small but non-significant difference in the number of students transferring the science concepts in challenging tasks. However, when student learning dispositions were taken into account, this increase in transfer of learning found within the high challenge pedagogy group was highest in those students with average CLARA scores in Belonging, Collaboration, Hope and Optimism and Curiosity. For students with high CLARA scores, the pedagogy made little difference in their transfer of the targeted concept. Small sample sizes precluded statistical analysis of the differences found. The impact on transfer of a range of other factors was described, both individually and in combination with pedagogy.

As with other studies in the long history of transfer research, this study did not produce conclusive evidence of either a single factor or even a combination of factors that can be exploited to deliver transfer of learning. Instead, it described a complex web of interacting factors that together, and undoubtedly in combination with others not included in this study, affect when, where, and what students transfer. The implications for members of the education community at different levels are discussed. For teachers, these include the need for clarity around the targeted concept and the kind of transfer required to enable them to select appropriate pedagogy and give feedback addressing the needs of different learners. For students, the emphasis is on being actively involved in their own learning and making the most of feedback - self, peer, and teacher provided. For education policymakers, curriculum writers, and assessment item developers, ensuring consistency between the curriculum descriptions and the kind of transfer assessed supports teachers to make decisions about the most efficient and effective pedagogy. Finally, for transfer researchers, future research informed by a two-way exchange of information and expertise between the researchers collecting and interpreting data sets and the teachers and students providing that data might mean that the findings are potentially better placed to improve student learning outcomes.

Prologue

The quest for my holy grail of education

In 1994, after two years of secondary school teaching followed by 12 years of casual work as a science researcher and TAFE lecturer (not to mention raising three children), I decided to return to classroom teaching for a while. The principal of the primary school where I had been appointed ran through his well-rehearsed tour of the school, explained that I would be teaching a Year 4 class, and finished with his usual line:

> "Any questions? The only dumb questions are those you don't ask."

Taking him at his word, I explained that my Diploma of Education was 14 years old, that I had never taught in a primary school, and finished with:

> "So what would you like me to teach them?"

The principal did a credible job of not rolling his eyes and ushered me out of his office to a classroom where he explained the situation to a teacher, who was apparently the school's expert on all things to do with learning. The teacher looked like a rabbit caught in the headlights, but eventually, she rallied, climbed on a chair to retrieve a dusty folder from the top of a cupboard and handed me the school's only copy of something referred to as *The Attainment Levels (South Australia. Education, 1992)*. This volume turned out to be the current government document outlining what students in South Australian schools were supposed to know. I wisely decided not to ask my next question, which would have been:

> "How would you like me to teach it?"

Fast forward to 2011, through a variety of classroom teaching roles, two graduate certificates (in Science and Maths Teaching and Neuroscience in Education) and several stints at curriculum and course materials writing, and I found myself in a role as a teacher facilitator, tasked with helping other teachers to implement the then, new Australian Curriculum (ACARA, 2021a). This curriculum now answered my question about what to teach, but my question on how best to teach it had become an ongoing quest. In the intervening years, I had compiled a repertoire of pedagogical strategies, with some input from professional development, but in reality, mainly by trial and error. This group challenge seemed to interest kids; that worksheet bored even me; a particular practical task was clearly fun, but they did not learn anything, etc. Feeling a bit insecure about my lack of evidence-based practice, I asked my line manager a similar question:

"So, how do I know what exactly is best practice teaching?"

She did a similar rabbit in the headlights impression to the teacher 15 years ago and then produced a collection of policy documents and motherhood statements peppered with words like inclusive, engaging and personalised. I duly synthesised all of these into a single document and sent it back to her for confirmation that this was the line I was supposed to promote. Her response was enthusiastic, and with the embellishment of official letterhead, it became the new policy document for the district. I, however, felt like a fraud because I knew the document was useless to classroom teachers. A collection of high-level, desirable characteristics might allow you to identify what is not good practice but does not indicate what you should do in your classroom. I began to doubt that evidence-based information that could allow classroom teachers to best construct and deliver state of the art pedagogy even existed, let alone was accessible to teachers.

I also knew that this holy grail of best-practice pedagogy would not be a recipe. I had seen plenty of these, Primary Connections (Australian Academy of Science, 2012) and Program Achieve (Bernard, 2001), for example, all telling you what to say and do as you worked through their step by step instructions. I had made several attempts to implement these faithfully and was embarrassed by my failure to stick to the script. No doubt to the frustration of the people I had agreed to trial programs for, I always ended up diverging from the plan provided when something did not gel with either myself or my learners. So as well as being rigorously evidence-based, best-practice pedagogy needed to be flexible enough to allow teachers to adapt it to their individual skills and interests, those of their students and the changeable conditions of the learning environment.

My quest continued through three related discoveries, each coincidently beginning with the letter "T".

1. Transfer of learning
2. Transdisciplinary ideas
3. Translational research

The first "T" - Transfer of learning

A few years later, I took up an opportunity to embark on a PhD as part of a group with an interesting sounding name, the *Flinders Centre for Science Learning in the 21st-Century*. My original training was in science, so I was comfortable here, and the *Learning in the 21st-Century* part offered the promise of something new and innovative rather than a rehash of the old. By now, I knew that I wanted my research to be directly relevant to all classroom teachers and the range of students they catered for in their classes, as distinct from the needs of particular groups. I read around the work of Carol

Dweck on mindset (Blackwell, Trzesniewski, & Dweck, 2007), John Geake on fluid analogies (Geake, 2009) and Slavin, Drake, Hanley and Thurston (2012) on thinking strategies and began to cobble together a research proposal incorporating all of these. In the process, I noticed the continual recurrence of references to transfer of learning. I am using 'transfer of learning' in a broad sense here - as the use of learning somewhere other than where it was learnt. This covers any use, any learning and any situation (further clarification of definitions is covered in Chapter 2.2). In the work of the researchers above, transfer was an indicator of deep learning and an outcome of meta-level strategies.

Transfer of learning is a powerful concept. I realised that transfer of learning was not only how we assessed students in tests, assignments and exams, but also the overarching purpose of the whole system within which I worked. If the outcome of schooling is not the capacity to transfer learning beyond the school context, then arguably, as teachers, we are doing little more than babysitting. Yet as a construct, transfer of learning seemed to receive little attention. I began to wonder what might happen if we looked at education through the lens of transfer of learning. Transfer of learning as a construct also has its challenges. Its ubiquitous nature has been the cause of debate amongst researchers (Mestre, 2005), with some dismissing it as so broad as to offer no potential for useful research findings since it includes the whole of human behaviour. Mestre (2005) takes the view that it is important to be specific about the scope of the transfer being investigated. How transfer of learning is conceptualised in this work evolved over the nine years part time of the study, and the final version (for now anyway) is described in detail in Chapter 3.2.

The second "T" - Transdisciplinary thinking

By transdisciplinary, I mean thinking about concepts that span the traditional areas of learning (disciplines). Transdisciplinary is different from multidisciplinary, where you look at a topic like natural disasters or the Olympic Games from the perspectives of different disciplines, perhaps taking an arts perspective on the opening ceremony and a STEM perspective on stadium design. It is also different from interdisciplinary thinking, where expertise from different disciplines is brought together to produce a single solution to a problem. The COVID 19 vaccine rollout required input from scientists to develop the vaccine, public health experts to plan the rollout and media professionals to advertise it to the population. My use of transdisciplinary refers to types of thinking that in being common to more than one discipline can bridge the gaps between separate disciplines. You can think critically or creatively, for example, in the arts, mathematics, science and technology.

As a process, transfer of learning is a key part of transdisciplinary thinking. It is the mechanism by which transdisciplinary concepts are interpreted in different disciplines, extending their range of application. In addition, transfer of learning is a transdisciplinary topic on its own. It is not confined to science but applies to other academic learning areas and a range of professional, vocational, recreational and everyday learning. Nor is transfer of learning confined to a particular set of learners, but is equally relevant to learners of all ages, stages and backgrounds. We learn, intending to use that learning at least somewhere else. Faced with a situation requiring a response, we invoke past learning and interpret it in the current situation to produce that response. Our cumulative set of responses to situations, our transfer of learning history, defines us as somebody who can provide a particular perspective such as science, ethical, original, inclusive etc., in responding to a situation. Transdisciplinary concepts can be powerful. As a primary school teacher with six or seven learning areas to cover, transdisciplinary concepts offer connections between the separate ways of thinking of the different learning areas. Different perspectives on the same ideas may increase the chance of learners transferring these ideas to other situations.

But transdisciplinary concepts have their challenges. In addition to their own conceptual knowledge, different disciplines come with their own ways of thinking about and communicating this knowledge. For example, evidence is seen differently by historians, scientists and musicians. This means that to consider transdisciplinary concepts, you have to suspend your commitment to the thinking of your preferred area of expertise to engage with what the transdisciplinary concept might look like in another discipline. In producing this thesis, the difference in perspectives between science educators and scientists who educate became evident and, at times, hard to reconcile. I have also found there to be implications for communicating these concepts as you cannot assume that the audience will have common disciplinary knowledge or thinking. What might be a necessary explanation to those without particular disciplinary expertise may seem redundant or patronising to those with this expertise.

The third "T" - Translational research or citation to classroom

By translational research, I mean the kind of research which takes findings from studies by university researchers sited in laboratories or simplified contexts and applies these in complex, real-world situations. One side effect of the COVID 19 pandemic has been to raise the profile of translational research in medicine as the media reports progress with vaccine development and changes to recommendations on how they are to be delivered. Many people are more familiar with clinical trial phases and the need to change recommendations in light of findings about side effects. For educators, these real-world situations are classrooms where teachers and students are going about their everyday business of teaching and learning. In general, education lags behind medicine in the use of translational research (Mitchell, 2016). There are programs, like Primary Connections and Program Achieve mentioned above, where the developers have integrated evidence from a range of research findings into a prescriptive set of instructions for teachers, but fewer examples of where researchers have set out to investigate a more general principle or principles in real classroom settings. This is what I set out to do – to investigate transfer of learning and how it might support learning outcomes in ordinary school settings. According to Mitchell (2016), translational research is often carried out by interdisciplinary teams, for example, with educators developing classroom interventions and scientists designing the trials and analysing data. As someone with postgraduate qualifications and professional experience in both science and education, I decided I was in a position to take on both of these roles.

Translational research can be powerful. It can identify ways in which research findings can benefit the general population. The methods used can provide educational practitioners with examples of how findings might be implemented in a classroom, and the findings themselves can provide evidence of the degree to which strategies work. But, like transfer of learning and transdisciplinary thinking, translational research comes with challenges. These include turning research findings into programs that might work in classrooms, controlling variables in the complex, variable and changing school environment, and obtaining ethics approval to run the trials. All these are complicated by the school year calendar, which offers a narrow window in teachers' planning for the year when they might consider involvement in a research project. Miss that window, and it is another 12 months before it comes around again, playing havoc with university degree progress as measured by milestones.

It would not be a quest if it were not fraught with challenges.

The quest continues

One criticism teachers have of some researchers they might hear at professional development sessions is that they have lost (or perhaps never had) touch with the complexity of what it is like to be in a classroom of 30 kids daily. The research evidence might be impressive, but if teachers can see no clear way to implement it in their settings, it will not benefit their students. As a deliverer of professional development to teachers in schools, I have indeed been called to task, with questions like:

> "How do you expect me to do … when I have already got … happening in my classroom?"

While some of this may reflect resistance to change or unwillingness to take a risk, many teachers express genuine frustration with increasing administration loads, the complexity of student learning needs and extracurricular activities. At the beginning of this project, I decided that to have any chance of presenting research findings that teachers might adopt on an ongoing basis, I needed to remain firmly grounded in the reality of classroom teaching. Therefore throughout the nine years as a part-time researcher of transfer of learning, I have kept up, at least to some degree, a role involving classroom teaching. Maintaining these two parallel roles has been demanding on my time and energy and runs the risk of appearing not committed to either, but, at least in my own head, each gives me credibility in the other. My professional development of teachers is informed by research, and my research on transfer of learning is grounded in past and ongoing classroom experience.

Over the course of this project, I have trawled literature from education and psychology for findings that might have relevance to transfer in primary science classrooms; I have written, rewritten and rewritten again science learning materials to test these findings in a typical classroom environment; I have tested tasks, questions and assessment tools in my classrooms; I have sat on the floor with groups of kids as they explained what they were thinking when they produced responses to test questions; I negotiated ethics approval to run the field trials of these materials; I adapted the experimental design in response to school settings and feedback from teachers and students, and finally I assessed (in many iterations) over 7 000 student work samples for evidence of transfer of learning. After all of this, the question arises as to whether my holy grail (best practice pedagogy) is available for all to see. And the answer is:

"Well, it depends …."

It turns out that best practice pedagogy is not like a silver cup that sits on a shelf but is as difficult to delineate as water running off the shelf, evaporating into the air and changing as it dissolves substances it comes into contact with. In a way, the answer was under my nose all the time. Learning Design (Government of South Australia, 2014), the government planning document, describes effective teacher practice as both intentional and responsive. It is intentional in seeking clarity about the learning, the learners and the conditions under which it is to be learnt and used, and responsive to variations in these. However, now I have evidence to explain why it is intentional and responsive and to illustrate what this might look like in a classroom. This thesis describes my investigations into state of the art pedagogy through translational research into the transdisciplinary concept of transfer of learning.

1 Introduction

1.1 Transfer of learning and education

Transfer of learning is arguably the main reason why we educate children. If our students cannot use what they have learnt in situations other than where they learnt it, then schooling is doing little more than babysitting. Despite this, transfer of learning as a construct is confined mainly to the periphery of the dialogue and artefacts of education at every level from policy to classroom. Transfer of learning is also how student learning outcomes are assessed in the short term. Every test item, assignment question or class contribution requires students to transfer something previously learnt to produce a response. The research presented in this thesis made transfer of learning front and centre to investigate the factors that affect what learning students transfer in a range of situations.

There are multiple definitions around transfer of learning (see for example Detterman (1993, p. 4) and Schwartz, Bransford and Sears (2005, p. 3)) which are reviewed later in chapter 2.2. From these a broad definition has been adopted for this thesis. Learning refers to anything that has been learnt and includes, but is not limited to, skills, knowledge, concepts, and attitudes. It includes content specified by a curriculum and learnt as part of formal education and incidental learning as part of everyday life. Transfer refers to the act of invoking and applying this learning in any situation other than where it was learnt, again including formal education and everyday life.

1.1.1 Transfer of learning and educating for a changing and less predictable future

To illustrate the role of transfer of learning in educating for a changing and less predictable future, I have developed the following hypothetical:

Imagine an island somewhere in the Pacific Ocean. Alarmingly for the inhabitants, the island appears to be sinking, but science advises that the explanation is actually rising sea levels due to global warming melting the polar ice caps. It is clear that the island will become submerged and uninhabitable over a short to midterm time frame, but exactly when this might happen is not predictable. In a rare display of unity, the UN Council for Sinking Islands has commitments from all member countries to resettle the displaced inhabitants in groups. Who will go where will be decided by ballot. Thus students in school can expect to continue their education and working life in any one of 200+ countries. They will take family support but expect to face differences in at least some areas such as the education system, language, culture, climate etc. You are asked to advise the teachers of school students on the island on:

a) *What should students be taught to best prepare them for their changing and unknown future?*

b) *What would you hope to achieve for the students because of this?*

c) *How would you teach it to have the best chance of those outcomes?*

d) *How would you know if the students had learnt what was taught?*

Over the eight part-time years of this research, I have posed this hypothetical to friends, family and colleagues. Predictably, how they answer these questions depends on their expertise and view of the world. My bioinformatician daughter gives a high priority to maths in enabling people to understand their world, while an art teacher friend believes that learning the arts will help people find something within themselves to use when times are challenging. Encouragingly, given their training, educators have clearer ideas than non-educators about teaching and assessing. In broad terms, though, the questions from the hypothetical prompt key aspects of educators' work:

a) Describes curriculum – what is to be learnt;
b) Describes transfer of learning – what students might be able to do with what they have learnt;
c) Elicits views on pedagogy – how might we teach the curriculum to maximise the chances of the outcomes in b); and
d) Describes assessment, which is also transfer but in a context much closer to where it was learnt than b).

Although the work of educators is not limited to these four aspects, they constitute a major part of their role as educators and transfer of learning features in two of them. Transfer of learning is both the mid and long term desired outcome of educating students, and the way progress towards that goal is assessed in the short term. For example, science teachers might aim for the outcome that as well as transferring recently learnt science concepts to the end of unit test, their students also transfer them to appropriate situations in their work, home or further education.

For most children in Australia, the future is not quite as uncertain as described above. Most students will probably not be subject to compulsory uprooting and migration to a new country. However, there are parallels in that they face a future that is changing and less predictable in many ways, and the question of what we hope to achieve for our students by a school education is just as pertinent. The desired outcome of education is learning that can be transferred adaptively in students' future lives. If this were not the case, then arguably, schools serve little purpose other than babysitting.

Awareness of a changing and less predictable future is not new, as the following examples show. Released in 2010, Ken Robinson's animation about Changing Education Paradigms[1] described a mismatch between a western schooling system and the outcomes needed by the young people it is educating. Modelling and predictions about the changing nature of work in Australia by the Committee for Economic Development in Australia (CEDA, 2015, p. 645) predicted that the increasing capacity of machines to effectively and efficiently take over activities performed by people means that computers will replace as many as 40% of jobs over the next decade or two. This work also pointed to changes in the way work is conducted, where the use of Information and Communication Technology expands competition and reduces both costs to consumers and workers' income. More recently, the unpredictability of the future was further illustrated in the massive disruption to work and education caused by the COVID-19 pandemic. Given the experience of the past few decades, it seems likely that our current students will experience employment and technology that we have yet to conceive. The South Australian Minister for Education (cited in Conner, 2021, cover) points out the need for students with transferrable STEM skills in the economic future as the world recovers from the global pandemic.

The question for educators then is how to prepare students to be successful in this future. This preparation involves the content of what to teach, both domain-specific knowledge like maths and history and generic, cross-domain skills like collaboration and critical thinking, and how to teach so that students can use it appropriately in situations we cannot yet envisage. The latter is the essence of the transfer problem facing teachers: how do we teach so that students can use the learning in meaningful ways in the short, mid and long term future, i.e. this year's National Assessment Program test, next year's classes and their world beyond school?

[1] https://www.youtube.com/watch?v=zDZFcDGpL4U`

1.1.2 Transfer of learning and educators' work

This thesis involved research on transfer of learning by students in South Australian primary schools. It should be noted that with the exception of data from national and international standardised tests, the data presented in this thesis is from relatively small, local samples in South Australian primary schools. In the documents that govern and inform practice in South Australian Schools, there is indirect rather than direct reference to transfer of learning. For example, from the current national goals of education, the Alice Springs (Mparntwe) Education Declaration:

> "Education …supports young people to realise their potential by providing skills they need to participate in the economy and in society, and contributing to every aspect of their wellbeing." *(Council of Australian Governments Education Council, 2019, p. 2);*

and from the current national curriculum, the Australian Curriculum[2]:

> "an Australian Curriculum will contribute to the provision of a world class education in Australia by setting out the knowledge, understanding and skills needed for life and work in the 21st century" (ACARA, 2021a);

Phrases such as "skills needed to participate" and "skills needed for life and work" make it clear that learners are expected to be able to transfer what is learnt in school to contexts beyond school.

In addition to these national policy documents, the South Australian Department for Education has produced a framework to support reporting on student learning, describing students' understanding of content, competence in using skills and capacity to apply them in new contexts (Department for Education, 2016). Transfer of learning is directly referenced in the verbs, use and apply, and implicit in the verb, understand, since students' understanding of content is demonstrated when they invoke and use it after learning. Thus transfer of learning is an expected outcome of teaching and learning in South Australia. Not only is transfer how students' achievement of the curriculum outcomes are measured in the short and medium-term, but it is also the medium and long-term rationale for educating students.

[2] Australian Curriculum and Reporting Authority

1.1.3 When transfer of learning fails

Since successful transfer is a desired goal of education, the converse or students' failure to transfer is of concern at many levels. Headlines such as "Australia drops in PISA rankings"("Australia drops in PISA rankings: Should we be worried?," 2019) and "South Australian students behind national average in NAPLAN testing" (Australian Broadcasting Commission, 2014) draw the attention of educators and the general public to students' failure to transfer the anticipated learning in large scale standardised testing.

At a classroom level, the quote below from an educator documents the frustration felt by teachers when students fail to transfer what is expected. Aside from transfer in the form of rare, spectacularly creative insights, it is failure to transfer and the ongoing frustration caused to educators and researchers alike that may receive more attention than everyday cases of successful transfer.

> We teach the students all the skills and knowledge needed to be able to do the task.
> We model and provide them with examples of how to do it.
> We give them practice to use the skills and break it down into steps.
> But when it comes to them putting it all together to produce a piece work or apply the skills and knowledge more often than not something doesn't gel or click and the work they produce does not reflect or meet the required expectations.
>
> As a teacher it is extremely frustrating and disheartening because you question yourself and your ability... What is it that I'm missing? What is it that I didn't do? What more do I need to do in order for these kids to be able to achieve what they need to achieve? How do you get it all to gel together so they get it?[3]

The teacher quoted above alludes to instances when learning acquired in the classroom is not transferred to other relevant contexts within the classroom. Perkins and Salomon (2012) also described other instances documented by researchers where knowledge learnt in the education system has failed to transfer to situations outside the system. For example, Richland et al. (2012) found that most graduates of schools in the USA are unable to transfer flexible maths concepts, reverting instead to memorised procedures regardless of whether they make sense in the context. Perkins (2009) described a physics class where students failed to transfer what they had learnt about objects falling from heights to the same objects falling down holes. And similarly, in another study by

[3] South Australian Primary School Principal (2015) personal communication

Cui, Rebello and Bennett (2006), despite believing that the maths calculus course had set them up with the necessary skills to use in physics, many students failed to transfer these skills to problem-solving in physics.

Given the central positioning of transfer in the theory and practice of the system in which they work, it seems reasonable and responsible for educators to consult research scientists for findings on which factors might improve (and inhibit) transfer of learning. Educators are faced with a specified body of knowledge (a curriculum), a group of learners (a class), and a set of assessment practices (tests, exams and portfolios) to measure what curriculum content the learners can transfer after being taught by educators. Every day, educators ask students to transfer in and transfer out. Students transfer *in* learning from previous experience, for example, yesterday's science lesson, last year's mathematics and their combined school experience of working collaboratively. Educators also aim to set students up to transfer what they have learnt *out* to tomorrow's lessons, next week's assembly and the camp later in the year. For educators, transfer of learning and factors affecting it are real and significant issues in their work on a daily and yearly basis. There is potential for research into the factors affecting transfer of learning to identify for educators how transfer may be optimised.

1.2 Transfer of learning and research

The idea that experience or learning in one situation can affect behaviour in another is neither new nor unique to education. Ohlsson (2011, p. 16) pointed out that what psychologists refer to as transfer goes by induction to logicians and projection to philosophers. Transfer of learning is a much-researched subject. In April 2021, a database search for *transfer of learning* or *transfer of training* yielded thousands of results from both educational and psychology journals. A search for these terms in the abstract field of the E.R.I.C. database yields over 18,000 results, including 3,212 reports, 700 theses or dissertations and 373 books. The wealth of published material attests to the theoretical and practical significance of transfer.

One of the earlier reviews of transfer research claimed that "There is perhaps no more important topic in the psychology of learning than transfer of learning" (Ellis, 1965, p. 5). Nearly 50 years later, in the introduction to another collection of papers devoted to transfer, the authors described transfer as "one of the most challenging, contentious and important issues for psychology and education" (Day & Goldstone, 2012).

Between the two, there are many attesting to the importance of transfer. For example;

> "In a sense, transfer is the Holy Grail of educators" (Resnick, 1989);
>
> "Educators believe transfer is the most significant issue" (Halpern & Hakel, 2003);
>
> "There continues to be a census that transfer is fundamental to all learning" (Haskell, 2004);
>
> "Absolutely central to educational enterprise" (Marton, 2006); and
>
> "Transfer is useful in that regularities in past experience continue to operate in the future" (Ohlsson, 2011, p. 16)

And more recently:

> "Transfer of learning is a pervading concept that is intrinsically linked to the way we lead our lives every day." (Leberman, McDonald, & Doyle, 2016, p. 1).

Leberman et al. (2016) argued that transfer pervades all aspects of our lives and is critical in the lifelong learning needed to adapt to times of rapid change.

Transfer has been approached from different perspectives, one of which relates to psychology and is perhaps more theoretical in approach. Early research described the goal as "to develop a comprehensive theory to integrate the variables affecting transfer" (Ellis, 1965, p. 5), while in later research, transfer informed investigations into other topics in psychology such as attention and memory (Woltz, Gardner, & Gyll, 2000), knowledge representation and analogical reasoning (Goldstone & Day, 2012). Transfer provides what Barnett and Ceci (2002, p. 613) described as a "testbed for theories of learning and performance".

Another perspective relates to education, often with direct relevance in informing educational practices. Ellis (1965) described the role of educational psychologists as designing programs that maximise transfer. Barnett and Ceci (2002, p. 613) described the practical significance in maximising "the time and money invested in education to cultivate general skills that transfer beyond educational institutions". Gray and Rebello (2005, p. 157) pointed out that widespread use of the slogan, teaching for transfer, attests to the increasing awareness of transfer as a goal of education. In May 2021, a search of the database E.R.I.C. for the specific phrase *teaching for transfer* yielded 57 results (45 journal articles, four books and four theses) where researchers have considered the term important enough to be keywords in their publication.

Yet another perspective on transfer is that of workplace trainers, concerned with transfer from professional learning to workplace practice. These researchers are usually dealing with transfer of learning between situations quite similar to each other and have taken a more functional view with the catchphrase: *what works?* Regular reviews (Blume, Ford, Baldwin, & Huang, 2010; Dori & Sasson, 2013; Leberman et al., 2016; Tonhauser & Laura, 2016; Whittington, 1986) have identified a range of factors relevant to the context of workplace training.

From the late 20^{th} century researchers involved with artificial intelligence (Reed, 2015) and second language learning (e.g. Baker, Basaraba, Smolkowski, Conry, Hautala, Richardson, English, & Cole, 2017; Thomas & Mady, 2014; Zhang, Koda, & Leong, 2016) also contributed to transfer research. This steady flow of transfer research from various perspectives has resulted in considerable diversity in the way transfer is conceived and the findings of this research (Day & Goldstone, 2012). The plethora of diverse and sometimes contradicting definitions, models, and findings led to general disenchantment with transfer research, summarised by Marton (2006) when he pointed out that the topic of transfer has over the last half of the 20th century changed from being much researched to much criticised. The criticism stemmed from how the concept of transfer is envisaged with the two extremes described as, on the one hand, rare to virtually non-existent (Detterman, 1993), and on the other, ubiquitous (Mestre, 2005). Detterman cited numerous research examples where subjects failed to demonstrate transfer of knowledge and concluded that people should be taught exactly what they were expected to use. Mestre, on the other hand, coming from the perspective that all human activity is based in some way on prior experience, suggested that the question is not whether transfer occurred but what was transferred. Day and Goldstone (2012) reviewed a range of alternative perspectives on transfer, describing them as designed objects, with the suggestion that different perspectives may serve different purposes (Lobato, 2012).

1.3 Connecting educators and researchers

The question arises as to what researchers' findings can offer educators in their mission to support students to adaptively transfer learning acquired in formal education to future situations, both in and beyond school. At present, there are some opportunities for interaction between researchers and educators. Although much research on transfer of learning has been carried out in university laboratories using undergraduates as research subjects, some researchers have ventured into schools to test their hypotheses in classroom settings (for example Engle, 2006; Jaakkola & Veermans, 2018; Peters, ten Dam, Kocken, Buijs, Dusseldorp, & Paulussen, 2015). Educators, especially those in curriculum leadership positions, may hear about research findings potentially applicable to classroom settings. In South Australia, visiting academics, including Dylan Wiliam from University College London and Jo Boaler from Stanford Graduate School of Education, have been recent speakers on formative assessment and mathematics pedagogy. While these offer the educators in the audience access to the ideas in the context of the presentation, and some may translate into action in classrooms, there is still evidence that teachers in South Australia are not using pedagogy that optimises transfer of learning by their students (Foster, 2020).

In their introduction to a 2012 collection of papers on transfer of learning, Goldstone and Day (2012) identified "transfer the existence of specific, validated techniques for teaching to facilitate students' transfer of their learning" as one of the emerging themes. From the experience of teachers described in 1.1.3, there is still room for these specific, validated techniques to be translated into classroom practice.

1.4 Outline of this research

The purpose of this research is to investigate factors that influence transfer of learning to inform the strategies used by educators to equip students best to be transferors of learning in the 21st-century. The initial research question was: *What factors affect transfer of science concepts by South Australian primary school students?* A literature review yielded a range of factors previously investigated for their impact on transfer of learning, but very few of these had been investigated with primary school aged students (5-12 years old) and even less in regular classroom situations. Thus the gap addressed in this project was to investigate transfer of learning by primary school aged students in their regular classroom setting. After investigations using existing evidence of transfer of science concepts by primary school students, the two subsequent experiments moved beyond the description of factors to describing the impact of these factors on the transfer of science concepts. The research question for the two experiments was: *How do factors relating to the students themselves, the concepts, the way these concepts were taught, the way transfer is measured together affect transfer of learning.* The hypothesis was that productive struggle and expansive framing should improve students' transfer of science concepts as they promoted engagement with the concepts in greater depth.

It is translational research in that it seeks evidence of the impact of strategies with promising research findings on transfer of learning in South Australian classrooms. The purpose of conducting the research in classrooms was to provide better evidence for educators about which findings might be effective in improving students' transfer of science concepts. A second benefit might be the provision for educators of classroom tested examples on how factors identified in laboratory research might be translated into classroom strategies. The investigations into these factors involved primary school students, predominantly in Years 5 and 6, the final years of primary school in South Australia. The research investigated their capacity to transfer learning in preparation for the change to secondary school. The learning in this research was the science concepts specified by the mandated curriculum for each group. The aim was to provide evidence that might inform the strategies used by teachers to support the development of transferrable learning in their students. This thesis is structured in seven chapters:

- Chapter 1 introduces the role of transfer of learning in education, especially in educating students for a rapidly changing and unpredictable future. It also looks briefly at the importance placed on transfer of learning by researchers from a range of perspectives and the plethora of conceptualisations of transfer and resulting diversity in research findings;
- Chapter 2 reviews the current research findings on transfer of learning from an educator's perspective. It starts by surveying the range of definitions, taxonomies, models and theories that have been used to delineate and map transfer of learning and then settles on versions of these to be adopted in this thesis. Then follows a brief look at the history of transfer, especially findings that might be relevant to educators, and an outline of research methodologies that have been used to investigate transfer;
- Chapter 3 sets out the definitions and frameworks constructed for this study to describe the components of transfer of learning and variation in transfer factors. These components include the learning itself, the tasks providing opportunities for students to demonstrate transfer and how transfer is measured. There are three broad groups of factors covered,

those related to the original learning, those related to the transfer of that learning and finally, those related to the students themselves.

- Chapter 4 describes three qualitative investigations into the transfer of science concepts by primary school students, mainly in Years 4 to 6, the final years of primary schooling in South Australia. All three investigations use existing artefacts of the education system. The first describes the transfer of science concepts in four standardised test items, while the second and third look at transfer in classroom tasks. The second investigation looks specifically at the transfer of a chemical science concept by Year 5 students, while the third takes a broader view of transfer of chemical science concepts by students across the eight years of primary schooling. Together they describe a picture of existing measures of transfer of chemical science concepts by a group of primary school students.
- In Chapter 5, the focus moves from seeking transfer in existing artefacts to experiments investigating the effect of different versions of pedagogy on the transfer of science concepts by students in Years 5 and 6. The first is a small scale pilot study involving the transfer of chemical science concepts by Year 5 students, carried out to evaluate the classroom program and materials developed to investigate the impact of pedagogy on transfer. Following this, a more extensive field study investigated the effect of two different pedagogies on the transfer of science concepts by Year 6 students. Informed by the process in the pilot study, this experiment was designed to investigate the effect of two contrasting pedagogies differing in the degree of challenge offered to students. In addition to data on students' transfer of science concepts, a range of other data was collected related to other factors such as student learning dispositions and motivation that might have affected transfer. This study was designed to offer the opportunity to investigate multiple factors and potential combinations of factors.
- Finally, Chapter 6 discusses the implications of the findings of these studies for teachers and other members of the education community.

Appendices at the end of the document include the research materials used in classrooms by teachers and students.

1.5 The impact of this research

During the nine years of this research, I was employed as a curriculum manager and Senior Learning Improvement Leader with the Department for Education in South Australia, three years in Learning Improvement Division and classroom teaching and six years in a partnership of five metropolitan primary schools. Over this time, I engaged with office colleagues, school leaders, teachers and students. My two roles were interwoven in that my experience working with teachers and their students informed the research, and my research informed my work in schools.

One impact of my research has resulted from the materials developed for the classroom experiments. These have been used to provide frameworks and exemplars for discussion about low and high challenge pedagogy, assess student work samples for evidence of learning at different levels of complexity, and develop and modify classroom task tasks. Together they have allowed for a common language in discussing these across the five schools of Mitcham Plains Partnership (accounting for 200+ teachers and 2500+ students).

The second area of impact relates to the findings from the literature review and the experiments. In particular, for these five schools:

- Teachers are aware of the difference between low and high challenge pedagogy, and not only is the term productive struggle part of the partnership vocabulary for leaders, teachers and students, but its role in promoting learning outcomes is now more generally understood.
- Teachers have developed their capacity to assess student responses for more complex and connected ideas rather than the number of simple items correct.
- Teachers have developed and modified extended response tasks to generate work samples from which student learning can be assessed.
- Students are aware that, for at least some of the time, their teachers are actively seeking to change the way they teach to improve student learning outcomes.

As with all change initiatives, there has been varying uptake. For some teachers, I have seen a transformation in the way they teach, and together we have worked to redesign how lessons and assessment might look and how their students can be accountable for their own learning. A current version of lessons stages for schools is included in Appendix A. Other teachers have given it a go to varying degrees and may continue to use it at times while not abandoning the tell and practice pedagogy they are comfortable with. And of course, there is a group whose engagement has been perfunctory and who are either firmly committed to other pedagogies or change-resistant.

For this education community, the impact has been to increase awareness of an alternative to low challenge pedagogy and demonstrate that it can operate in classrooms like theirs. To capitalise on this, the focus on pedagogy at all levels of the education community and blend of pressure and support offered in the five years of the school-based Learning Improvement Leader's tenure would need to continue so that the momentum was not lost and the focus shifted.

1.6 Original contribution to knowledge

This research is translational in that it takes relatively generic research findings on transfer of learning and seeks evidence of their impact in a context that is not well represented in transfer of learning research, the transfer of science concepts by upper primary school students. The first original contribution to knowledge comes from the materials developed for the study, as these have application to classrooms beyond the study, including for teachers of students of levels other than upper primary and subjects other than science. In particular:

- The distinction between targeted and grounded transfer clarifies the difference between formative and summative assessment and emphasises the importance of responding to prior knowledge;
- The classification of the factors affecting transfer allows teachers to identify what they can influence and what they need to work around;
- The concept outline offers clarity around the concepts targeted by the curriculum;
- The task difficulty matrix offers a way to assess existing tasks for their degree of challenge and modify them to increase or decrease this for different learners;
- The grounded transfer matric offers a way to assess student responses to a transfer task and indicates the feedback needed to continue their learning;
- The evidence of engagement framework offers a way to maximise learning from student reflections so that they move beyond superficial aspects of the process or their emotional response to focus on what and how they learnt.

The second original contribution to knowledge comes from the findings from the experiments. The pilot study finding provides evidence that productive struggle led to significantly more far transfer of the properties of gases concept in challenging tasks than tell and practice pedagogy. Although the findings were not significant, the odds ratios in the field trial also point to the effect of high challenge pedagogy on transfer of the electrical energy flow concept. The field trial also outlined a range of interconnected factors affecting transfer, which indicates that rather than a simplistic solution of manipulating one factor to improve transfer of learning across the board, a more nuanced version would consider the interactions of factors related to the learning, the transfer task and the learners themselves. Together these findings have direct application to classroom programs and suggest areas where further research may yield more insight into how transfer of learning might be optimised in the complex context of school classrooms.

2 Literature Review

2.1 Overview

This thesis focuses on factors affecting the transfer of science concepts by primary school students. The research is translational in that it investigates the impact of applying research findings to classroom settings where students are engaged in their everyday learning programs, so the literature review serves to identify research findings relevant to transfer of learning in a primary school science setting. However, before this can be undertaken, clarity is needed around the construct of transfer of learning and how it might be interpreted in a classroom setting. This clarity is necessary as a point of reference to ensure consistency when designing interventions, measuring transfer and interpreting the resulting data.

This literature is presented in thematic sections. The first three (chapters 2.2,2.3,2.4) clarify the construct of transfer of learning to be used in this thesis, the next three (chapters 2.5,2.6 and 2.7) survey research findings for potential classroom application and the next (chapter 2.8) compares transfer research methods. The final section (chapter 2.9) identifies the gap in knowledge that this thesis sets out to address:

Section 1 (chapter 2.2) *Definitions of transfer of learning.* This section aims to delineate the concept by considering what has and has not been considered as transfer and identifying the main components of the construct. A range of definitions and conceptions of transfer that researchers have used are compared, and potential applications of different versions of these are considered;

Section 2 (chapter 2.3) *Taxonomies of transfer of learning.* This section describes variation within these components of transfer by looking at the range of ways in which researchers have classified different types of transfer. Some of these classifications have more relevance to this classroom-based research than others;

Section 3 (chapter 2.4) *Models and theories of transfer of learning.* This section looks at how researchers have described the transfer process by suggesting relationships between the components identified above. The relationships often involve other aspects of psychology such as noticing, attention and memory and aim to account theoretically for how transfer occurs in some instances and not others.;

Section 4 (chapter 2.5) *Factors affecting transfer of learning*. The research surveyed in this section is findings from experiments where researchers aimed at identifying the impact on transfer of learning of particular factors. These include factors that educators can control, such as pedagogy, factors they might influence, such as student learning dispositions, and factors over which they have little influence, such as curriculum content. As comparatively few studies have used the same context as this study (science concepts by Year 5 and 6 students), the survey included studies that involved different learning and different learners as some of these may generalise to the context of this study;

Section 5 (chapter 2.6) *Failure to transfer* Here the review looks specifically at failure to transfer and the various constructs and findings around this.

Section 6 (chapter 2.7) *A selection of transfer of learning research findings.* While the previous section looked specifically at research into the factors affecting transfer of learning, this section sought other research findings relevant to educators. It examines the changing and diverging focus of transfer research over 100 years;

Section 7 (chapter 2.8) *Transfer of learning research methodology.* In this section, attention is turned to how thransfer research has been conducted. Four different research methods used by researchers are compared for the data used, the way this data is interpreted and the potential findings from each; and

Section 8 (chapter 2.9) *Conclusion.* Here I describe the gaps in knowledge about transfer of learning that need to be addressed to empower educators to prepare their students better to transfer concepts.

2.2 Definitions of transfer of learning

With regards to the research question: What factors affect transfer of science concepts by South Australian primary school students? the purpose of this section is to clarify what is meant by transfer for this thesis.

Given the variety of backgrounds and perspectives of researchers who have worked on transfer of learning, it is unsurprising that there is no general agreement on how the phenomenon of transfer is defined. This makes the challenge of gleaning from research literature findings useful in classroom research even more complex. This section surveys the plethora of diverse definitions used by researchers and identifies two with potential application to transfer of learning in classroom settings.

In one of the earliest publications on transfer research, the transfer question was described as "How far does the training of any mental function improve other functions" Thorndike (1903, p. 80). Thorndike (1903) was concerned with the distinct initial learning and subsequent use situations, particularly the similarities between them, concluding that transfer only happens when people detect identical elements between the two situations. Five years later, Judd (1908) referred to transfer as "the generalisation of experience", considering transfer of learning as expanding the range of contexts where the learning can be applied. The challenge of reconciling diverse perspectives became no simpler over the century of research that followed, and the literature abounds in definitions, conceptualisations and descriptions of transfer of learning, a range of which are shown in Appendix B – A Range of Conceptions of Transfer of Learning These are presented in chronological order, throughout which several themes recur. These themes are shown in the headings of columns three to six.

The range of definitions captured in Appendix B – A Range of Conceptions of Transfer of Learning illustrates that there is not a single widely applicable and universally accepted definition of transfer, but rather a range of conceptions of transfer across different researchers reflecting their individual perspective on the issue. The definitions adopted by researchers may include reference to any or all of:

- What is transferred (column 3) - something stored in the mind of subjects or learners, referred to as mental contents by Helfenstein (2006) but also commonly as learning, knowledge or training. Curiously, only rarely is reference made to memory;
- The actions of learners during transfer (column 4) – sometimes observable behaviour, such as apply or use, and other times referring to mental processes, such as activate, apperceive or generalise;

- At least two contexts (column 5) - one or more associated with initial learning or experience and one or more associated with subsequent activation of that learning. The term context is broad, and as well as features of the task, it may encompass factors of the physical and social environments, including instructional techniques, perceived authority and consequences, and peer influence; and
- Reference to similarities or differences between the contexts (column 6). Some researchers specify that there need to be significant differences between the context(s) in which the mental contents were acquired and that in which their activation is being investigated. Time difference is one of these, and, as well as *new* and *other*, words like *past, prior* and *future* are sometimes used to distinguish contexts.

Definitions from cognitive science researchers focused on the knowledge or skills that were or were not transferred (Alexander & Murphy, 1999; Cui et al., 2006; Detterman, 1993; Woodworth & Thorndike, 1901), referring to the acquisition and use of these skills. Research commonly targeted a particular skill or concept and set out to identify conditions under which it is transferred. While this approach continues to be used by some researchers, increasingly, researchers with a socio-environmental background offer definitions taking into account the perspective of the individual doing the transferring (Bransford & Schwartz, 1999; Greeno, Smith, & Moore, 1993; Lobato, Rhodehamel, & Hohensee, 2012). These socio-environmental versions are much less specific about what is transferred, referring to past experience, and broader in scope as they seek evidence of transfer in combination with other learning. Their criticism of the cognitive science perspective is that transfer defined by expected skills or concepts is based on experts' behaviour and is rarely found in learners (Gray & Rebello, 2005). Evidence of the wider view of transfer includes learners' steps along the way to becoming experts and is therefore much more commonly found.

In addition to the wide range of conceptions of transfer, there are those who see no future for it as a research topic. Hager and Hodkinson (2009) proposed that the metaphor of transfer is too simplistic for the complex set of interconnected processes that make up transfer and should therefore be abandoned. As mentioned earlier, Detterman (1993) considered it an epiphenomenon, a function derived from other more fundamental processes. A range of other suggestions have been put forward to replace transfer, including productive thinking (Hatano & Greeno, 1999), preparation for future learning (Bransford & Schwartz, 1999), apperception (Helfenstein, 2006), generative learning (Marton, 2006) and transformation (Larsen-Freeman, 2013).

For this thesis, two different perspectives on transfer were relevant in different ways to the transfer demonstrated in classrooms. The cognitive science view was used when working with summative assessment and is referred to as ***targeted transfer.*** Targeted transfer is here defined as the *activation and adaptive application of curriculum concepts in non-rehearsed situations*. This addresses the question of whether the student transferred the targeted concept in a particular task in a way that is consistent with the curriculum. The tasks, or non-rehearsed situations, could be classroom conversations, tests and assignments or tasks from external assessing bodies. By specifying that transfer of the targeted concept should not have been rehearsed in the new context, this definition attempts to avoid the difficulty of defining how different the two contexts need to be to be considered transfer. This leaves the way open for transfer to quite similar contexts but also means it will be necessary to identify how similar or different the two contexts are.

However when working with formative assessment to provide feedback to learners this view does not acknowledge the range of knowledge other than the targeted curriculum concepts that students might demonstrate. For these situations, a more socio-environmental view was taken and referred to as ***grounded transfer,*** here defined as the *range of prior conceptions that learners activate and apply in a situation.* This allows a more constructivist view where curriculum concepts are incorporated into learners' existing repertoire of thinking resources. Table 2-1 compares the two definitions of transfer of learning used in this research. Columns 2 to 5 correspond to those used in Appendix B – A Range of Conceptions of Transfer of Learning to compare definitions from other researchers.

Table 2-1 Comparison of targeted and grounded definitions of transfer

Definition	What is transferred	Behaviour (what they do with it)	Contexts (Where and when)	Similarity/difference	Application for educators
Targeted	curriculum concepts	adaptive application	situations (tasks)	unrehearsed - any context they haven't worked with the concept before in.	summative assessment
Grounded	range of prior conceptions	activation and application (both adaptive and maladaptive)	situations (tasks)	any context	formative assessment for feedback and planning of learning

2.3 Taxonomies and classifications of transfer

With regards to the research question: What factors affect transfer of science concepts by South Australian primary school students? the purpose of this section is to outline the variation in transfer of science concepts that might be exhibited by the primary school students.

In defining transfer of learning, three key areas of focus were identified and described in Table 2-1:

1. the learning;
2. the actions of the learners in producing evidence of transfer; and
3. the contexts in which the learning and transfer occurred, especially similarities and differences between them.

If the purpose of these definitions of transfer of learning is to delineate the phenomenon as a whole, then the purpose of a taxonomy or classification is to account for the variability within the phenomenon of transfer of learning. A classification of the variation in each of the three areas listed above could provide a reference for educators to compare different instances of transfer of learning and consider models or theories to explain transfer. As research into transfer expanded both in quantity and in the range of perspectives encompassed, it became clear that at least some of the contradictory findings were because researchers were investigating different types of transfer.

One of the earliest and most persisting distinctions was between near and far transfer (Mayer, 1975; Royer, 1979), relating to the degree of similarity between the contexts of learning and use. Royer (1979) for example, defined near as from school context to school context, while far was from school context to a context outside of school. The dimensions of what constituted near and far eventually became so diverse that Barnett and Ceci (2002) published a paper setting out nine dimensions of transfer, six of which related to the contexts in which the learning and transfer occurred. They then analysed a range of key studies in transfer, among which there were contradictory outcomes, demonstrating that different dimensions of near and far had been involved. Evidence for the academic influence of near and far as a classification of transfer lies in the 1,838 citations of Barnett and Ceci's paper according to Google Scholar (as of June 2020).

Near and far were also used by Haskell (2004) to distinguish transfer of training from transfer of learning. Of the two, transfer of training required reproduction of learnt, relatively basic material in situations very close to that in which it was taught. He identified 11 different criteria contributing to this distinction and noted that the shift from an industrial age training model to an information age learning model was beginning to have an impact on workplace training as well.

A range of other classifications of transfer is listed in Appendix C – A Range of Classifications of Transfer of Learning. Each has been used as a framework for explaining at least one set of experimental results or real-life transfer context. Some overlap or appear to be slightly different takes on the same thing; e.g., the specific/ nonspecific and literal/ figural both seem to address the degree of similarity in learning being transferred. In fact, similarity between learning or contexts is a recurring criterion. The numbers in brackets in column 3 refer to the three components of transfer described on page 20. The comments in column 6 provide extra information to help compare the classifications, and the final column considers the direct relevance for educators. The classifications collected in Appendix C – A Range of Classifications of Transfer of Learning draw attention to the range of different dimensions of transfer of learning used by different researchers for different purposes. Not all of them are relevant or easy to apply to instances in either research or education settings. For example, Royer, Mestre and Dufresne (2005) pointed out that it is easy to define near, specific and literal transfer but much harder to define far, nonspecific and general forms of transfer and (Haskell, 2004) admitted that his 14 types of transfer are not mutually exclusive. Some, such as the coordination class of DiSessa (2002) and the kinds of transfer proposed by Calais (2006), use discrete categories, while others, such as the dimensions of transfer proposed by DiSessa and Wagner (2005) and the near/far distinction of (Royer, 1979), imply a gradient between extremes. Although when outlining their taxonomy, blurred and overlapping distinctions between different kinds of transfer were addressed by Barnett and Ceci (2002) using a gradient rather than distinct categories, they reverted to a categorical near or far when classifying studies for comparison.

2.3.1 Variation in the learning transferred.

The two definitions described in Table 2-1 were constructed to describe the transfer of learning that happens in classrooms, and so to describe variation in instances of this transfer, the same three components are considered: the learning transferred; the actions of the learners in doing the transferring and the contexts in which the learning and transfer occurred. Here I look at variation in these three components.

Several classifications in **Error! Reference source not found.** addressed differences in the learning argeted for transfer (Benander, 2018; Calais, 2006; DiSessa & Sherin, 1998; Royer, 1979; Wolfe, Reyna, & Sears, 2005). These differences offered a range of sometimes overlapping categories, some related to different memory systems such as declarative or procedural, while others coming from an education perspective, used categories such as disciplinary and inter-disciplinary. As part of their taxonomy of transfer, (Barnett & Ceci, 2002) included three dimensions under the content heading: learned skill, performance change, and memory demands. Only the learned skill described the knowledge or learning transferred. They distinguished three subcategories of learned skill;

procedure, representation and principle, of which principle is closest to the science concepts chosen as the learning to be transferred in this research.

A framework related more directly to an educator’s perspective on transfer is the *coordination class* described by DiSessa and Sherin (1998) and DiSessa and Wagner (2005). Coordination, in this instance, referred to how different elements of knowledge about a concept are related. DiSessa and Wagner worked with a targeted definition of transfer: the “reuse of knowledge acquired in one situation in another”, with “knowledge” in their research referring to concepts or parts of concepts from tertiary level physics. The parts of concepts, which they referred to as *phenomenological primitives*, were distinct ideas transferred as a whole, such as speed, mass, etc. Their research commonly involved qualitative data from interviews over a period of time, during which they traced the transfer of developing concepts such as force by looking for evidence of the coordination of these different parts of the concept. Their framework, called a coordination class, is described in Table 2-2. The first five columns paraphrase the coordination class as described in DiSessa and Wagner (2005); the final column shows how this was interpreted in the classroom research described in this thesis.

Table 2-2 Coordination class framework

Elements of a coordination class (after DiSessa and Wagner (2005))					Interpretation of these elements in the classroom research for this thesis
Level I	Core function			The purpose of the concept	What is the purpose of the concept? Why does it exist?
Level II	Intrinsic difficulties		Span	Operation of the concept across a full range of appropriate contexts	Which contexts does the concept apply to?
			Alignment	Identification of the same relevant information in different situations	What is the same about these contexts in relation to the concept?
Level III	Architecture	Function	Readout strategies	The focusing on relevant information from different situations	What needs to be attended to in the context?
			Causal net	Inferences used to infer the defining information from that which has been read out	How does it work? What rules and patterns are there?
		Processing	Incorporation	Extending previous conceptions to include the new concept	How is previous learning built on for this concept?
			Displacement	Dismissing previous conceptions which are not relevant to the coordination class.	What from past learning is not helpful in this concept?

DiSessa and Wagner pointed out that the framework does not necessarily apply to all concepts, or even all science concepts. The coordination class framework has been used by a number of researchers, e.g. (Barth-Cohen & Wittmann, 2017; Dufresne, Mestre, Thaden-Koch, Gerace, & Leonard, 2005; Levrini & diSessa, 2008; Ozdemir, 2013) to interpret transfer in a range of contexts.

2.3.2 Variation in the actions of the learners doing the transferring

A dimension of learners' behaviour identified by Barnett and Ceci (2002) was that of memory demands. This describes how the learning is cued by the context, with the lowest demand where the learning is directly cued as in a task like: *Use the theory of tectonic plates to explain how this earthquake occurred*. The cuing may be less blatant than this. Asked the question: *How likely is Adelaide to have a serious earthquake?* in a science class as part of a unit on tectonic plates and the environment is likely to prime students towards invoking the concept of tectonic plates. At the other extreme, learners may have to search their memory for relevant learning and decide which is most appropriate before applying it, as if, for example, the same question was asked in an English class analysing media reports on an earthquake elsewhere.

Another classification of the transfer behaviour distinguishes between transfer involving the reproduction of knowledge pretty much as learnt from transfer in which a more general idea is interpreted in a new context, variously described as literal/ figural by Royer (1979) and verbatim/ gist by Wolfe et al. (2005). Richland et al. (2012) found that drilling learners in reproducing rote learnt causal nets eventually leads to automaticity but inhibits transfer to new contexts.

The difference between the behaviour of learners and experts described by DiSessa and Wagner (2005) as three classes of transfer, distinguishes the apparently effortless application of experts from the effortful attempts of novices to choose and apply appropriate learning in an unrehearsed context. The intermediate class described the actions of successful learners who have not yet reached expert status, the most likely product of successful classroom instruction.

In addition to these contributions from cognitive science, others available to educators and researchers outline a hierarchy of learner behaviours. Examples include the revised Bloom's taxonomy of educational objectives (Anderson, 2001) and Marzano's new taxonomy of educational objectives (Irvine, 2017), both of which have been used by educators in South Australia, especially in distinguishing tasks requiring higher levels of thinking. Bloom's taxonomy offers six categories to describe a task:

1. Remember – retrieving knowledge from memory;
2. Understand – determining meaning;

3. Apply – carrying out a procedure in a situation;
4. Analyse – identifying parts and the relationship between them;
5. Evaluate – making judgements against criteria; and
6. Create – combining parts to make a new product.

Marzano and Kendall (2007) recognise four levels of complexity student learning:

1. Retrieval – recognition, recall and execution of procedures;
2. Comprehension – identify critical features of knowledge, integration and symbolisation;
3. Analysis – makes inferences that go beyond what was directly taught; matching, classifying, analysing errors, generalising, predicting; and
4. Knowledge utilisation – uses knowledge to address real-world issues; decision making, problem-solving; experimenting; investigating.

Two taxonomies that do use learner behaviour to infer learning outcomes are the Structure of the Observed Learning Outcome (SOLO) (Biggs & Collis, 1982) and Depth of Knowledge (DoK) (Webb, 1997). These two taxonomies interpret demonstrations of learning in terms of increasingly complex thinking. Webb's DoK was designed to measure consistency in learning outcomes between different educational jurisdictions in the USA and offers four levels of increasing cognitive demand into which student responses to tasks may be classified.

Also addressing student response to the task is the SOLO taxonomy (Biggs & Collis, 1982). In its original form, there were five modes based on those suggested by Piaget (sensory-motor, ikonic, concrete-symbolic, formal, and post formal) and five levels of increasing complexity within each mode.

The structural elements of the two taxonomies are compared in Table 2-3.

Table 2-3 Comparison of Depth of Knowledge and SOLO taxonomies of learning outcomes

DoK level	SOLO level
No corresponding level	Pre-structural - no evidence of target learning
Level 1 - Recall and reproduce	Uni-structural – one relevant idea
Level 1- Recall and reproduce	Multi-structural – more than one relevant idea, but with limited connections between them
Level 2 - Skill or concept used to answer questions	Relational – identifies the link, rule or pattern between the separate ideas and collapses parts into a whole
Level 3 - Strategic thinking – planning justification and complex reasoning	Relational
Level 4 - Extended thinking – how else can this be used in real-world contexts?	Extended abstract – can use the link rule or pattern in different contexts and as a basis for further learning.

In the nearly four decades since its original publication, SOLO has evolved from the contributions of researchers. Chan et al. (2002) suggested three sub-levels in each of the original multi-structural and relational levels to resolve ambiguities. Pegg and Tall (2005) and (ACARA, 2021b); Panizzon, Arthur and Pegg (2006), working with science learning outcomes of secondary school students, split in the concrete symbolic mode into two cycles corresponding to everyday learning and learning using technical or scientific ideas to get a finer-grained measure of thinking. SOLO has been used to inform documents at a system level (e.g. Australian Curriculum (Authority, 2017), National Assessment Program tests (ACARA, 2021b)).

2.3.3 Variation in the contexts of learning and transfer

Although the idea of near and far transfer referring to differences between the learning and transfer contexts had been around for some time, a key contribution in clarifying this came with the six dimensions described by Barnett and Ceci (2002). These can be interpreted readily in educational contexts, as described in the second column of Table 2-4. Column 3 describes some additions to cater for non-targeted transfer - the everyday learning that learners bring to learning and transfer situations.

Table 2-4 Dimensions of near and far contexts

Dimension (Barnett & Ceci, 2002)	Examples of this variation in a school setting	Additions for everyday learning transferred in or out to
Domain of knowledge	Learning areas	Everyday knowledge
Place	A range of classrooms and other learning spaces, as well as off-campus locations like camps and excursions.	Home, community and holiday locations
Time	Lesson, week, month, term, year	Unspecified past time that learner may or may not be aware of
Functional context	Learning, low stakes assessment, high stakes assessment	Every day, real life
Social context	Individual, pair, small group, large group, society.	Difference in group dynamics, e.g. collaboration, support, competition, expectations
Modality	Familiar/ unfamiliar formats; same/ different formats	Wider range of examples with each format

Barnett and Ceci provided examples of the extremes of these dimensions, but quantifying or even ranking different instances across a group of learners is difficult because of the range of experience, dispositions and attitudes that individuals bring. The same printed text, for example, might be a familiar and comfortable format to one learner but might entail significant amounts of effort for another to decode before invoking past learning.

The dimensions used by Barnett and Ceci related to the environment external to the task. Another group of researchers have looked at internal variation in the task context (Catrambone & Holyoak, 1989; Day, Motz, & Goldstone, 2015; Son & Goldstone, 2009; Spencer & Weisberg, 1986). They have distinguished between abstract and concrete contexts (Day et al., 2015) and simplified contexts versus those including distracting detail (Harp & Mayer, 1998). These task features offer ways to describe how difficult it is for students to transfer in particular tasks.

2.4 Models and theories of transfer

With regards to the research question: What factors affect transfer of science concepts by South Australian primary school students? the purpose of this section is to examine some theories and models of transfer proposed by other researchers. These models and theories have the potential to shed light on the process of transfer shown by these students and hence inform teaching strategies to optimise transfer.

So far, this review of the literature related to transfer of learning has addressed definitions to get clarity about the phenomenon as a whole and considered taxonomies or classifications to describe the variability within the phenomenon of transfer. Here the focus moves to models and theories that have been designed to explain the interactions and relationships between the learning, the learner's behaviour and the two contexts to inform how transfer can be optimised in educational settings.

In contrast to diversity in definitions and taxonomies, transfer models have much in common at one level when it comes to models and theories. Transfer is about similarities - identifying and acting on similarities between contexts. Learners need to see similarities before they invoke the learning from the previous context and apply it to the current. We have seen these similarities variously described as identical elements (Thorndike, 1903), stimuli and response (Ellis, 1965), regularity and production rules (Singley & Anderson, 1989), situations or contexts (Forbus, Gentner, & Law, 1995; Vendetti, Matlen, Richland, & Bunge, 2015), affordances (Greeno, 2006) and deep and surface structure (Chi & VanLehn, 2012). In the simplest form, similarities are identified, again variously described as attended to, noticed, detected, seen and perceived, before previous learning about these similarities is applied to produce a response. This perspective is often labelled *associationist* (Leberman et al., 2016, p. 10).

A slightly different emphasis from the search for similarities focuses on generalising skills and concepts from one area to others. Some of the earliest research on transfer focused on generalising cognitive skills from the classical curriculum areas such as algebra and Latin to other curriculum areas (Thorndike, 1924; Thorndike & Woodworth, 1901). Although Thorndike (1924) found little evidence for this between high school subjects, the model of transfer as a generalisation of knowledge has persisted. Transfer researchers who came from a cognitive perspective considered transfer to be seeing new contexts as instances of generalisations they already have. These generalisations may be analogies (Gentner & Holyoak, 1997; Holyoak & Koh, 1987; Holyoak & Thagard, 1997), coordinated knowledge pieces (DiSessa, 2002; Taatgen, 2013) or deep structure (Chi & VanLehn, 2012). However, extending generalisations requires seeing similarities between a new context and a past instantiation of the generalisation, so the associationist and cognitive models seem to collide.

Disenchanted with these two models' failure to predict or explain transfer consistently, other researchers have taken different perspectives. The situated perspective considered the environmental (Hammer, Elby, Scherr, & Redish, 2005; Vermeulen, 2002) or social (Beach, 1999; Lave, 1988) conditions under which the transfer takes place and positioned transfer as an expansion of the contexts where learning is applied. Other perspectives have focused on the learner, as in the actor-oriented transfer of Lobato (2012), where transfer was an expansion of the learner's experience. The corollary was that all experience is relevant for consideration as transfer, not just that involving targeted concepts. Researchers in case studies have used this view (Cui et al., 2006; Gray & Rebello, 2005; Roorda, Vos, & Goedhart, 2015), and it is relevant to classroom research in that it acknowledges the range of prior knowledge, misconceptions, irrelevant ideas and limited understanding that learners bring.

Finally, there are a group of professionals operating with a functional perspective. While acknowledging the range of models and theories generated by transfer research, their concern is what works and when. Many of those with a functional perspective come from workplace transfer of training, and the term *model* applies more to a recipe for getting the desired transfer from training to workplace and less about the mechanism for transfer (Leimbach, 2010; Yelon, 1992).

A range of examples of transfer models is shown in Appendix D – Examples of a Range of Models of Transfer of Learning.Despite their different perspectives, a common element of all models is context. Learners may search for similarities between contexts, extend their range of relevant contexts, operate within a wider social and environmental context or selectively notice elements of contexts. Focusing on surface details of context may be a quick recipe for near transfer, but for far transfer, learners need to look for underlying structure (Chi & VanLehn, 2012).

For educators, a useful distinction in models of transfer comes from the low road/high road classification (Salomon & Perkins, 1989) and the three classes of transfer (DiSessa & Wagner, 2005). These researchers distinguished differences between the transfer pathways occurring in the instantaneous, apparently effortless transfer that characterises experts in the field of the targeted knowledge (high road /Class A), compared to the effortful, inefficient and time-consuming transfer typical of novices (low road/ class C). DiSessa and Wagner (2005) also described an intermediate category, Class B transfer, which requires some degree of effort and time to eventually arrive at successful transfer. The case studies described by DiSessa and Wagner (2005) of the development of physics concepts showed the slow progression in developing this level of transfer in tertiary students. For non-experts, the transfer process enacted requires an effortful search through the context for similarities with past learning and evaluation of the potential of the learning connected to these to deliver an adaptive response in the context. This is Class C transfer, where learners have little to no experience with the learning needed. With experience, Class C transfer moves to Class B transfer as learners begin to acquire and connect the knowledge pieces needed. In a school setting, Class A, B and C describe the transfer of teachers, successful students and beginning or unsuccessful students respectively.

Because of the time needed to achieve it, expert-level transfer is rarely found in the relatively short time frames of research (Schwartz et al., 2005) or classroom units of work. Researchers and educators alike lament its absence. Broadening the goal to include the range of learning that learners do invoke allows the model to describe what learners are doing when they exhibit Class B and C transfer. Included then is any learning which:

- is consistent with the targeted learning but not sufficient (limited);
- is not consistent with the targeted learning (misconceptions); or
- addresses an alternative thread to the targeted learning (missed the point).

The effortful process involves following similarities that turn out to be maladaptive or dead ends and so developing the coordination class in successive approximations of expert level.

Researchers from the situated transfer perspectives (both social and environmental and a combination of the two) have included evaluation steps where the learner decides whether to continue to work with the current affordance or change direction to a potentially more fruitful option. This step is the *elect* of Day and Goldstone (2012) and the *sense-making and sufficing* of Nokes-Malach and Mestre (2013). Nokes-Malach and Mestre (2013) proposed this in an iterative process which proceeds until the sense-making and sufficing criteria have been met.

From the cognitive perspective, other researchers have looked at the initial detection of similarities. Both Lobato et al. (2012) and Chase, Malkiewich and S. Kumar (2019) drew attention to the importance of noticing, and Helfenstein and Saariluoma (2007) considered transfer to be apperception or seeing as.

One aspect of research that has widespread uptake in education is related to learners' beliefs about intelligence, goals and approaches to learning, commonly known as mindset, and summarised by Duff and McKinstry (2007) and Dweck and Yeager (2019). While transfer was not the focus of the mindset research, it was used as a defining characteristic of deep compared to surface learning by researchers in many fields (Maciejewski & Merchant, 2016; Miki & Yamauchi, 2005; Ramburuth & Mladenovic, 2004; Trenholm, 2021). From the findings of the mindset researchers, memorisation as a learning strategy has become associated with surface learning and failure to transfer. However, Wu, Carstensen and Lee (2020) pointed out that this is an oversimplification and that memorisation associated with metacognition can be adaptive.

This review has outlined a range of models developed by researchers to explain the process of transfer. Aspects of these were applied in interpreting the findings of the research in chapters 4 and 5.

2.5 Factors affecting transfer

With regards to the research question: What factors affect transfer of science concepts by South Australian primary school students? the purpose of this section is to review findings on factors which might affect transfer investigated by other researchers. This is the essence of the research question and informed which factors were investigated in this research.

In seeking insights about transfer of learning that might help educators be more effective in improving learning outcomes of their students, the interrogation of research on transfer of learning has so far yielded ways to describe and conceptualise transfer and this section uses these to interpret the research findings on factors that affect transfer. Here the term, factor includes variations in the three key areas of focus identified in the review of definitions (section 2.2) and described in the review of taxonomies and classifications (section 2.3). The factors identified might relate to one or more of three key areas: the learning, the actions of the learners, or the contexts of the learning and transfer. However, transfer of learning might also be affected by factors such as those related to the conditions of the learning experience or the learners themselves, neither of which align neatly with one of these three key areas. The classification of factors for this thesis is further clarified in Chapter 3.

Transfer research spans a wide range of learning, learners and contexts, but for this thesis, the learning was science concepts, and the learners were upper primary aged students (Years 5 and 6). Existing research in this combination of content and learners is relatively sparse since, although science as a learning area (especially physics) has attracted some research attention, most of the research subjects have been tertiary undergraduates. Some research findings relevant to science for learners close in age to Years 5 and 6 are summarised in Table 2-5.

Table 2-5 Research studies of transfer of science concepts years 4-8

Factor	Year level	Learning area	Improvement measured	Study
Expansive framing of the learning both socially and temporally	Year 5	Endangered species	Conceptual understanding in a transfer task	Engle (2006)
Generalisation across multiple contexts	Year 5	Endangered species	Conceptual understanding in a transfer task	Engle (2006)
Inventing with contrasting cases	Year 8	Physics	Transfer to unrelated topics with the same structure	Schwartz, Chase, Oppezzo and Chin (2011)
Spaced quizzing with feedback	Year 7	Science	Definition and application test items	McDaniel, Thomas, Agarwal,

				McDermott and Roediger (2013)
Digital interface giving learners control of a *plan, get data, explain* model with learning support and feedback on request	Year 4	Electricity	Knowledge of science content	Rappolt-Schlichtmann, Daley, Lim, Lapinski, Robinson and Johnson (2013)
Withholding stepwise instructions on how to solve problems	Year 6/7	Physics	Conceptual and PFL	Richey and Nokes-Malach (2013)
Student motivation, task concreteness and interest	Years 4-6	Electricity	Ability to reason in post-test	Tapola, Jaakkola and Niemivirta (2014)
Direct instruction in metacognition	Year 8	Physics	Confidence bias, Motivation, conceptual understanding test and performance on novel self-guided activity	Zepeda, Richey, Ronevich and Nokes-Malach (2015)
Contextualisation in context	Year 7/8	Science	Application of principle under test conditions	Day et al. (2015)
Regular self-assessment of competence and interest	Year 7/8	Life science and physics	Motivational goals	Bernacki, Nokes-Malach, Richey and Belenky (2016)
Explicit, hands-on instruction	Year 5-6	Science inquiry skills	Test and practical activity	Kruit, Oostdam, van den Berg and Schuitema (2018)
Concrete /fading concrete representations	Years 4-6	Science	Transfer test	Jaakkola and Veermans (2018)
Self-assessment and task selection training	Age 12	Biology/ maths	Performance on transfer task in another curriculuma rea	(Raaijmakers, Baars, Paas, van Merriënboer, & van Gog, 2018)

Most of the factors in this table could be described as conditions related to the learning experience, but also included are contextualisation referred to by Day et al. (2015), which could refer to either of both of the learning or transfer contexts, and student motivation and interest (Tapola et al., 2014) relating to the students themselves. Some factors, such as generalisation and contextualisation, are generic and could apply to a range of classroom strategies, while others, such as spaced quizzing and withholding stepwise instructions, refer more specifically to particular strategies.

While there are factors here with the potential to inform classroom practice, this represents a small subset of the research literature on transfer of learning. Casting the net more widely may offer potential factors which have not yet been investigated in this combination of learners and learning. Staying with this age group of learners, but widening the learning domain to include other curriculum areas such as Maths and English or general attitudes to learning, yields further factors related to the teaching and learning of concepts for transfer. Considerable research on goal theory has produced evidence (Boden, Zepeda, & Nokes-Malach, 2020; Chin & Brown, 2000; Law, Chan, & Sachs, 2008; Martin, Mansour, & Malmberg, 2020; Middleton & Midgley, 1997; Miki & Yamauchi, 2005; Ramos, De Fraine, & Verschueren, 2021) that mastery goals, incremental theory of intelligence and a theory of knowledge as constructed rather than reproduced, correlate with a suite of adaptive learning behaviours. This group of factors, sometimes collectively known as deep learning, or in South Australian primary schools as *growth mindset,* predict performance on transfer tasks (Bereby-Meyer, Moran, & Unger-Aviram, 2004; Blackwell et al., 2007; Chen, 2012; Chen & Pajares, 2010; Göçmençelebi, Özkan, & Bayram, 2012). By contrast, performance goals, surface learning, and fixed mindsets have mixed results. Performance-avoidance goals correlate negatively with conceptual understanding transfer (Middleton & Midgley, 1997), and performance-approach goals can be positive when performance is successful and negative when performance is not successful (Barron & Harackiewicz, 2003; Beck & Schmidt, 2013).

There are several key points to note from this research on goal theory for researchers and educators. Firstly, factors related to deep learning may moderate the effects of other interventions. For example, Kappes, Stephens and Oettingen (2011) found that students with an entity theory of intelligence (the view that intelligence is fixed rather than malleable) showed less improvement with interventions designed to improve learning performance. Secondly, entity theories of intelligence with the potential to interfere with learning, are not fixed but can be influenced through practices related to classroom goal structure (Bardach, Oczlon, Pietschnig, & Luftenegger, 2020; Yang, 2012), metacognition (Tzohar-Rozen & Kramarski, 2017; Zepeda et al., 2015), teacher framing of learning (Boden et al., 2020) and self-assessment (Bernacki et al., 2016), all of which a teacher can influence. This interaction between factors is an alert for researchers, as changing a single factor may not have the desired effect if it is moderated by other factors.

Other research focuses on factors relating to teaching and learning rather than the learners themselves. Increasing the cognitive work required of learners has been called productive struggle

(Warshauer, 2015), productive failure (Kapur, 2015) and desirable difficulties (Bjork, Little, & Storm, 2014). The term *productive failure* emphasises that success in the struggle part of productive struggle is not necessary for the strategy to improve performance on both well-structured and complex maths problems (Kapur & Bielaczyc, 2011). Critical thinking correlated with improved academic results in a study by Yang (2012). In a change from the methodology of interventions with students, critical thinking was taught to teachers who went on to incorporate it into programs for their students. Generalisation as a learning strategy was the target of research by (Ellis, 2007), who distinguished generalising actions (relating, searching for similarity and extending) from reflection generalisations (identifications, statements or definitions and the influence of prior learning).

If the field is widened to include all school-age learners (ages 5 to 18), then as well as further investigation of the deep learning complex of factors (Bardach et al., 2020; Duff & McKinstry, 2007), additions to the list of teaching and learning factors include productive failure (Hartmann, van Gog, Rummel, Leerstoel van, Education, & Learning: Development in, 2021) worked examples (Cooper & Sweller, 1987), students own explanations (Brown & Kane, 1988), explicit problem goals when learning (Chen & Daehler, 1992) and inventing solutions (Schwartz et al., 2011; Schwartz & Martin, 2004).

This list falls into several categories:

- Factors associated with the learning experience:
  - Factors related to the classroom management of the teachers, e.g. framing of the learning, classroom learning goals, both explicit and implicit, and management of social interaction;
  - Factors related to the learning tasks, e.g. contexts, cognitive demand, feedback;
  - Factors related to the degree to which learners are engaged in metacognition and taking control of the learning process, e.g. self and peer assessment; metacognitive strategies;
- Factors associated with the transfer task, e.g. time since learning; similarities in context between learning and transfer; distracting details; and
- Factors associated with the learners.

Finally, once the vast amount of research findings involving undergraduates as subjects and laboratory conditions rather than classrooms is included, a myriad of other factors appear. Many of these fit into the framework described above, expanding the repertoire of strategies in each category, but others are additions, untested on school-aged students possibly because of the difficulty in controlling variables in classroom research. In addition to the studies investigating a single factor, other studies have measured multiple factors and suggested that interaction between factors produces a more complex scenario.

Some of these are shown in Appendix F. This list represents a considerable extension of the range of factors from education research. Some such as contrasting cases (Chase et al., 2019), rule and example training (Fong, Krantz, & Nisbett, 1986), and misconception refutation (Beker, Kim, Van Boekel, van den Broek, & Kendeou, 2019) are readily adaptable to the classroom and able to be incorporated into teachers' repertoire of learning strategies. Others such as decontextualisation and recontextualisation (Peters et al., 2015), expansive framing (Hart & Albarracín, 2009), and mastery goal classroom talk (Boden et al., 2020) are principles suited to evaluating current practice but which need to be translated into classroom learning strategies for teachers to implement. The factors that in research had negative or zero impact on transfer include some common teaching practices such as explicit instruction before practice (tell and practice), investigations/discovery learning, and teaching in a concrete context.

The literature on factors affecting transfer of learning has suggested factors relating to three areas: the learning experience, the way transfer is measured and the learners themselves that have potential to impact on transfer of science concepts. The question for classroom research moves beyond listing the factors to investigating the impact they have both individually and in combination with each other. Of particular interest are factors relating to the teacher's pedagogy, since this is something researchers and teachers can potentially control. This is the gap addressed in the research in chapter 5.

2.6 Failure to transfer

With regards to the research question: What factors affect transfer of science concepts by South Australian primary school students? the purpose of this section is to address the converse of the research question by reviewing findings on students' failure to transfer. This relates specifically to the translational nature of this research as students' failure to transfer is a central issue for educators.

One area of research relates not to successful transfer but to learners' failure to transfer. The importance of this was raised in the introduction, and the ideas are further developed here. As well as being a frustration for educators, failure to transfer is also the bane of researchers. Detterman (1993), in a review of transfer literature, described many examples where researchers failed to get transfer, discounting those where subjects were given hints or instructions as to what to apply. Gick and Holyoak (1980) and Gick and Holyoak (1983), investigating conditions under which analogical transfer occurs, failed to get transfer without hinting that subjects needed to use the earlier examples to help them. Reed, Dempster and Ettinger (1985) did not get transfer between similar algebra problems even under a range of conditions designed to support this, and likewise, Bassok and Holyoak (1989) failed in many cases to get transfer between physics and algebra. More recently, Lipko-Speed, Dunlosky and Rawson (2014) failed to get transfer of science concepts in 5th and 6th grade students. In addition to the frustration for researchers, Larsen-Freeman (2013), from the perspective of transfer to and from second languages, noted that failure to transfer is an issue of social equity, disproportionately affecting lower SES students.

Failure of transfer has two different forms:

2.6.1 Inert knowledge

"Objects in motion remain in motion but come to rest in the playground." Here Linn (2002), cited in Perkins and Salomon (2012, p. 255), described the failure of ideas learnt in a science classroom to be used outside the classroom. The term *inert knowledge,* first used by Whitehead (1929), cited in Schwartz, Chase and Bransford (2012, p. 205), referred to knowledge that the learner has acquired but is not activated in situations where it would be useful. Chen and Pajares (2010) saw the failure of people to transfer beyond the school classroom as a major challenge for formal education, and it is a familiar issue to educators across a range of systems, including the educator quoted at the beginning of this section. Explanations for the role of inert knowledge in failure to transfer centre around the initial learning experience – that it did not support access to prior knowledge (Snoddy, 2018); did not lead to deep enough learning (Chi & VanLehn, 2012); or relied on an overuse of tell and practice methodology, which supports surface learning at the expense of deep learning (Richland et al., 2012). Abstract learning rather than learner-centred contextualisation has also been found to result in inert knowledge (Son & Goldstone, 2009).

2.6.2 Randomised controlled trials

Researchers from the traditional perspective adopted randomised controlled testing as their preferred methodology. Participants were usually university undergraduates in these experiments, most often enrolled in psychology courses, where participation formed part of their course requirement. Those enrolled in other courses, commonly science, often received a small cash payment for their participation. The content of the tasks and their performance often had minimal relation to their course of study and, although some researchers discounted data from students who appeared less than fully cooperative, the traditional transfer paradigm paid little or no attention to the dispositions or motivation of participants. Hendrickson and Schroeder (1941), investigating transfer of refraction of light principles to success in hitting underwater targets; Gick and Holyoak (1983), investigating the effect of different strategies for learning schemas on analogical transfer, and Goldstone and Son (2005), investigating the effect on transfer of learning in concrete and abstract contexts are just some of the many studies using this methodology. However, from an expanded view of transfer, the scenario above raises questions about the motivation of the participants to transfer. Using the engagement framework of Fredricks, Blumenfeld and Paris (2004), it could be argued that these students may have had behavioural engagement in the task, but their emotional and cognitive engagement was by no means as certain and could have contributed at least partly to their failure to transfer in many cases.

The learning task was often given as a reading task in a booklet; e.g., Gick and Holyoak (1983) or in later research on a screen (e.g. Goldstone & Son, 2005), with variables coming in the way the task was presented and what subjects were required to do to process the information. Attention was given to removing any outside physical or social context, and the transfer task was often of the same format. Subjects usually worked individually, even when other subjects were in the room. The intention was to remove all possible confounding variables so that differences in performance could be attributed to variables manipulated by the experimenter. Unable to control for variables associated with the prior knowledge and experience of the learner, these experiments often had larger numbers of subjects.

The measurement of transfer was usually binary - success or failure on one or several problem-solving tasks, and sometimes whether learners had used the targeted thinking to solve the problem.

2.6.3 Overzealous or negative transfer

Overzealous transfer (Schwartz et al., 2012) described a different kind of transfer failure, in which learning is applied, but to contexts in which it is not useful. This is over generalisation, where learners are not selective in what to transfer, resulting in responses that are not only maladaptive in the new context but may actually interfere with new learning. The concepts are often referred to as misconceptions or alternative conceptions, and to educators, they can be surprisingly resistant to change, representing significant blocks to learning. Ohlsson (2009) proposed a resubsumption theory to explain how these conceptions arise and the pedagogical implications for how they might be addressed. Gooding and Metz (2011) distinguished different types of misconceptions and pointed out that learners are unaware of them. Sadler, Sonnert, Coyle, Cook-Smith and Miller (2013) documented the effect teachers' misconceptions may have on their students' learning.

Schwartz et al. (2012) attributed some overzealous transfer in education settings to excessive tell and practice methodology and developmentally inappropriate teaching materials, especially when learners were not given early feedback on their efforts to apply new learning. The ability to distinguish contexts in which the concept can and cannot usefully be applied is the key to avoiding overzealous transfer. They distinguished between adaptive experts (virtuosos) who seek to understand the variability of new contexts, choosing and combining concepts adaptively, from routine experts (artisans) who routinely apply off the shelf solutions and hence are prone to overzealous transfer.

In addition to the frustration for researchers, Larsen-Freeman (2013), from the perspective of transfer to and from second languages, noted that failure to transfer is an issue of social equity, disproportionately affecting lower SES students.

2.6.4 Alternative perspectives on failure to transfer

The failure of students and experiment participants to transfer has been well documented in reviews of transfer (e.g. Detterman, 1993; Lave, 1988; Royer et al., 2005), with some reviewers, e.g. Detterman, concluding that transfer rarely happens, and consequently it is best considered an epiphenomenon (a composite of other more fundamental psychological processes). Moreover, it was claimed that further research is unlikely to yield insight into human cognition. McKeachie (1987, p. 707) used the word *paradoxical* to describe the contrast between transfer of everyday experience that happens all the time and the rarer transfer of learning targeted by educators and researchers. While some researchers have continued to search for the elusive factors that would promote transfer in educational and research settings, others have turned to reimagining the concept of transfer and what is being sought.

Researchers have taken a range of alternative perspectives. Hatano and Greeno (1999) proposed that transfer researchers have stacked the deck against themselves with narrow definitions of learning and separating learning and transfer tasks. In transfer situations, learners try to use knowledge already mastered in preference to that recently acquired and of which they are still unsure of its application. The resulting transfer might not replicate that sought by the researchers but is still evidence of the use of prior learning. They used the term *productivity* to describe the use of prior learning (Hatano & Greeno, 1999, p. 645).

Lobato et al. (2012) also suggested that researchers look more widely for transfer. Considering the learner's perspective, they pointed out that even though transfer, as defined by the researcher, may not have occurred, other pertinent transfer may have. They related this to the differences between novices and experts. Differences in knowledge structure affect what is noticed in transfer contexts and hence what learning is engaged to construct a response (Chi, Feltovich, & Glaser, 1981; Greene, Chinn, & Deekens, 2021). Thus researchers and educators may need to take a wider and longer term view to get beyond the phenomenon of short term failure of transfer.

Preparation for future learning (Bransford & Schwartz, 1999, p. 68) was also introduced as an alternative perspective on transfer. This perspective detects many instances of transfer, such as the sophistication of questions asked, that would pass unnoticed in the traditional direct application perspective. From yet another different perspective, Lave and Wenger (1991), working with apprentice and master craftspeople in several different communities, considered transfer as changing participation in a community as novices work their way from the periphery to the centre by acquiring skills.

The various perspectives on failure to transfer emphasise the value in classroom research of a grounded perspective on transfer. The information on what, other than the targeted concept, students did transfer has the potential to provide more detail on the impact of factors under investigation and hence lead to strategies to target specific issues.

2.7 A selection of transfer research findings

With regards to the research question: What factors affect transfer of science concepts by South Australian primary school students? the purpose of this section is to locate the specific instance of transfer of science concepts by primary school students in the broader field of transfer research.So far the literature review has focused on ways of thinking about transfer of learning and findings about the effect of specific factors, both of which informed the experiments described in Chapters 4 and 5 of this thesis. Before describing these experiments, this section seeks to put them in context by taking a more in-depth look at some of the key findings of research on transfer of learning.

Given the significance of transfer in education, the plethora of research findings and the elusive nature of definitive theories, it is not surprising that volumes of work reviewing transfer of learning have appeared regularly over the last 50 years. These reviews come in two forms – firstly, collections of research papers bookended with an introduction or summary which position the papers in an ongoing narrative as well as offer the editor's perspective (e.g. Detterman, 1993; Ellis, 1965; Grose & Birney, 1963; Mestre, 2005) and secondly, books designed as manuals for educators, particularly in the field of workplace training; e.g. Leberman et al. (2016). The key difference between the positions of workplace trainers and that of academic educators is that workplace trainers generally have a much clearer view of at least the immediate contexts in which the learning is to be applied. This simplifies their role to one of developing skills within a context similar to that in which they will be used, termed *hugging* by Perkins and Salomon (1992). In contrast, educators in schools and academic institutions are educating students for are more variable, less predictable contexts and need to rely more on generalities, termed *bridging* by Perkins and Salomon (1992). Hajian (2019) relates the same distinction between hugging and bridging to low road transfer in workplace training and high road transfer in education.

The chronology below follows the development of several key threads in the development of transfer research.

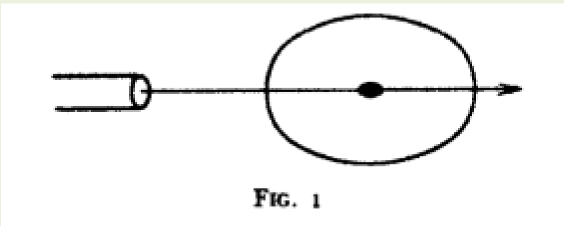
An early series of transfer experiments investigated transfer of skills like estimation of area, word identification and memorisation (Thorndike & Woodworth, 1901). In one of these experiments involving area estimation, six subjects failed to transfer a learned skill of area estimation from rectangles to other polygons. Thorndike and Woodworth concluded that transfer only happened if there were what they referred to as *identical elements* (Thorndike & Woodworth, 1901, p. 250) (in this case, rectangular shape) between the two situations. In searching for conditions that supported transfer, laboratory studies investigated a diverse range of cognitive skills, including applying refraction of light principles to hitting submerged targets (Hendrickson & Schroeder, 1941), using text organisation (Katona, 1942), developing decoding rules (Haslerud & Meyers, 1958). In a different approach, Thorndike (1924) analysed school and tertiary results for transfer between subjects. By 1965, researchers were still looking for the variables that determined transfer (Ellis, 1965). In the steady stream of research over 90 years between Thorndike's original paper and a review by Detterman (1993), hundreds if not thousands of studies on transfer were conducted (Detterman, 1993, p. 9) and most failed to demonstrate transfer (Detterman, 1993, p. 15). A comprehensive review of these studies is beyond the scope of this thesis, but in the section that follows, a subset of this large research body is used to illustrate the development of different perspectives on transfer research. This subset is defined as those studies which used a particular problem to study transfer.

2.7.1 The radiation problem – a microcosm of transfer research

In 1945 an English translation of the monograph on problem-solving written by German philosopher Karl Duncker (Duncker, 1945) was published. One of the researched problems came to be known as the radiation problem. A translation of Duncker's text and the accompanying diagram is shown in **Error! Reference source not found.** (Duncker, 1945, pp. 1-2).

Figure 2-1 Duncker's radiation problem (Duncker, 1945, pp. 1-2)

Given a human being with an inoperable stomach tumour and rays that destroy organic tissue at sufficient intensity, by what procedure can one free him of the tumour by these rays and at the same time avoid destroying the healthy tissue which surrounds it?



Duncker himself was interested in how people arrived at a solution to the problem, both the optimal convergence strategy of several lower intensity beams aimed at the tumour from different directions resulting in a sufficiently high intensity at and only at the tumour, and the range of less elegant solutions produced by subjects. However, the problem became a favourite tool of transfer researchers, appearing so regularly that the story of its use mirrors that of transfer research.

Gick and Holyoak (1980) wrote an analogous story, a paraphrase of which follows:

In the Attack-Dispersion story, a general wishes to capture a fortress located in the centre of a country. There are many roads radiating outward from the fortress. All have been mined so that while small groups of men can pass over the roads safely, any large force will detonate the mines. A full-scale direct attack is therefore impossible. The general's solution is to divide his army into small groups, send each group to the head of a different road, and have them converge simultaneously on the fortress.

This paraphrase allowed them to use one problem as a training problem for the strategy of converging many lower intensity rays on the target and the other as the transfer problem. They also wrote several disanalogous stories and analysed the points of similarity between their stories in detail. In a series of five experiments using groups of subjects (undergraduates) ranging in size from 27 to 143, they looked for transfer of the convergence strategy from the military story to the medical radiation problem. In common with Duncker's findings, transfer was rare unless subjects were given a hint to use the story to help solve the problem. The series of experiments showed transfer was increased when subjects had to produce their own solution to the military problem and decreased when disanalogous; distractor stories were involved as well as the analogous military story. Further experiments (Gick & Holyoak, 1983) found no improvement in transfer when subjects were given verbal or diagrammatic representations of the principle convergence strategy. However, transfer improved when diagrams were combined with several analogies depending on the quality of the schema subjects constructed from the analogies (Gick & Holyoak, 1983).

Using the same materials and experimental design, subsequent research confirmed that transfer between analogous stories was rare without hints (Spencer & Weisberg, 1986) and identified a range of conditions that would support or inhibit transfer. From these studies, it was concluded that transfer improved when:

- multiple analogous stories were used (Catrambone & Holyoak, 1989; Spencer & Weisberg, 1986), especially when stories were compared (Kurtz & Loewenstein, 2007);
- analogous stories were more similar to the target (Keane, 1987). The authors proposed a model for retrieving analogues from memory based on abstract, domain-independent organisation structures. Their solution path involved search processes;
- subjects were given a near-miss analogy and required to summarise similarities and differences (Gick & Paterson, 1992). The authors suggested this was due to highlighting the critical features;
- the source problem was encoded in terms of the relevant schema to the extent where a hint was not necessary if the problem was encoded well enough (Mandler & Orlich, 2013);

- a more similar visual representation was used (rays represented as bands of tinted transparent material fanned out from a central point) (Beveridge & Parkins, 1987) and when the diagrams were animated to emphasise the solution (Pedone, Hummel, & Holyoak, 2001);
- participants acted out the analogous source stories (Catrambone, Craig, & Nersessian, 2006), which authors attribute to added perceptual information; and
- subjects posed their own problem analogous to the source problem (Nikata & Shimada, 2005).

However, transfer was impaired when:

- disanalogous stories were included (Spencer & Weisberg, 1986); and
- the time delay between source and target stories increased from 45 sec to 6 minutes (Spencer & Weisberg, 1986).

Another thread of research featuring the radiation problem involved eye-tracking technology to infer attention differences as subjects attempted to solve the problem. Grant and Spivey (2003) found that successful problem solvers spent more time looking at the skin in the diagram, and when they used animation to draw attention to this, the rate of successful solutions increased. Increased success was also achieved by directing participants' attention in trajectories that crossed the skin from outside to the tumour (Thomas & Lleras, 2009) and when subjects followed the gaze of successful problem solvers (Litchfield & Ball, 2011). While some of these are technically not transfer from a source to a target problem, they raised the profile of attention and noticing in how learners perceive and process a solution.

The effect of individual differences in general characteristics of learners was further investigated by Antonietti and Gioletta (1995), who identified three characteristics of subjects that correlated with improved analogical transfer. These were testing well for field independence – the ability to extract structural details from the embedding concept; a tendency to improve their existing solutions rather than searching for new solutions; and domain expertise (biomedical students compared to humanities). By contrast, tests of non-verbal reasoning (Raven's Progressive matrices) and verbal or visual thinking preference showed no significant correlation with success in analogical transfer.

Helfenstein and Saariluoma (2005) focused on specific differences between learners in how they perceived the properties of radiation in the problem. They showed that the assumed perception of radiation as a narrow, parallel beam and the additive effect of multiple beams converging at a single point was held by a minority. Instead, radiation was perceived as chaotic, diffuse, diverging and hard to control, and although many applied an additive model to the effect to the tumour, this was less evident when they considered its effects on healthy tissue. With such variation in individual prior knowledge, the schema model of transfer is not sufficient to explain the variability in transfer outcomes.

Other researchers also took issue with the analogical transfer experiments. Lave (1988) critiques the whole notion of transfer by abstraction. In her view, knowledge is inseparable from the context in which it was acquired, and transfer consists of broadening the range of contexts to which it has been demonstrated to apply. She uses the example of an apprentice becoming increasingly more adept at using the skills of the trade in an expanding range of contexts as they are learnt from a master. Anderson, Reder and Simon (1996) cite the analogical transfer experiments as an example of looking for transfer where one is least likely to find it, that is, from little practice in one domain to initial use in another.

To Bransford and Schwartz (1999), using the radiation problem to measure transfer was an example of sequestered problem solving (SPS), problem-solving where learners are sequestered away from further learning, seeking resources such as texts or peers, trying things out and receiving feedback. They claim that this model of transfer as the ability to apply learning directly to a new context overlooks transfer that prepares subjects for future learning in a knowledge-rich environment, making the distinction between *knowing that* or *knowing how* in traditional transfer experiments and *knowing with* when transfer is viewed from the perspective of preparation for future learning (PFL).

Although the researchers of analogical transfer have not identified the fundamental variables that determine transfer, their research has provided several potential lines for educators to follow, including:

- Generalising from multiple examples;
- Active engagement of the learner in constructing representations of similarity;
- The variation in perspectives of learners;
- The role of the context in learning; and
- The effect of different representations.

Typically these experiments were carried out in laboratories, with subjects drawn from university undergraduates who participated as volunteers or for course credits or small cash incentives. These participants differed in age, motivation, education and general world experience from primary school students, and so the research findings may not automatically generalise to school classrooms.

2.7.2 Transfer of physics concepts

Another group of researchers who have also contributed to our understanding of transfer are physics educators. Because physics is often seen as a challenging subject and an understanding of physics concepts is a foundation for other areas of study from medical sciences to engineering, much research attention has been given to how students learn these concepts. This research is often partly conducted in classrooms and uses learning materials relevant to the learner. Factors identified by the work of physics educators are considered here in this section.

2.7.2.1 Novice and expert transfer

Some research findings were consistent with those of the analogical transfer researchers. The importance of knowledge structure in transfer was shown in research by Chi et al. (1981) and Chi and VanLehn (2012), investigating the difference between the perception of structure in physics problems by novices and experts. They found that both novices and experts see the relevant surface features, but unlike novices, experts could see deeper structure consisting of interactions between the surface features and then relationships between the interactions. They suggested that expert problem-solving structures should be investigated and made available to students. Brookes, Ross and Mestre (2011), investigating refraction of light, also found that students transferred superficial features of training in refraction at the expense of principles.

2.7.2.2 Concrete and abstract contexts

Bassok and Holyoak (1989) investigated the role of context in the transfer of concepts related to arithmetic progression between algebra and constant acceleration problems in physics. They found that while students who learnt in the constant acceleration context were unable to use the concepts to solve problems in algebra, those who had learnt in the relatively abstract algebra context were able to transfer to isomorphic physics problems. This transfer was reduced if the problems were embedded in a discussion of motion concepts. Studies by Kaminski, Sloutsky and Heckler (2013) and Day et al. (2015) reported similar findings. These results supported the proposition that generalisation beyond the immediate context supports transfer.

2.7.2.3 Teaching sequemce

Hsu, Kalyuga and Sweller (2015) compared the effect of two sequences of instruction: problem - example and example – problem, strategies similar to the productive failure described in chapter 2.5. While they found no advantage of students' being involved in problem solving before they saw worked examples, the authors also noted that the results may depend on the type of learning investigated. Their work involved learning processes while Kapur (2015) working with maths concepts found better results for the productive failure condition.

2.7.3 Learning strategies

Rather than generic principles, other research has investigated specific learning strategies that might help learners acquire this structure. Self-explanation, and the accompanying monitoring of their own understanding and misunderstanding, was found to be used by successful learners of physics problem solving (Chi, Bassok, Lewis, Reimann, & Glaser, 1989). Nokes-Malach, VanLehn, Belenky, Lichtenstein and Cox (2012) compared self-explanation with two other ways of learning from examples and found that reading and self-explanation did better on near transfer, all three strategies were the same on mid-range transfer, and analogy and self-explanation did best on far transfer. This is important for educators who are often concerned about the difference between what students demonstrate in classrooms at the time of learning (near transfer) and what they use in exams and other contexts (far transfer). Self-explanations are particularly promising in delivering results in both situations.

Other tactics which have shown success include teaching students to analyse problems by integrating concepts, principles and procedures (Mestre, Dufresne, Gerace, Hardiman, & Touger, 1993), asking students to use the examples to invent formulas before being explicitly taught them (Schwartz et al., 2011) and withholding instructional explanations for worked examples (Richey & Nokes-Malach, 2013). Mestre (2002) asked students to generate problems rather than solve them and found that when followed by an interview, it was a useful assessment tool for probing understanding and transfer with the potential to be applied to whole-class teaching.

For primary aged students, the generation of understanding from top-down or bottom-up perspectives has been mainly viewed as either one or the other. Students were either given the expert's structure and set to practice it (tell and practice) or allowed to experiment with materials to develop their own understanding (discovery). The above research suggests that both strategies are essential, but the order is critical. It might be beneficial for transfer if students attempt to construct a bottom-up understanding before they are given access to the top-down thinking used by experts.

Other researchers have looked at the actions of Science teachers. Using a large online survey, Sadler et al. (2013) found that students whose Science teachers knew common student misconceptions performed better but only for medium to high achieving students. Although there are questions around whether this study controls for the experience of the Science teachers, which may act in ways other than through their knowledge of misconceptions and how the more effective teachers used this knowledge in their classrooms, it does suggest that as well as the perspective of the learner, that of the teacher might shed light on student transfer.

2.7.4 Learning programs

Finally, education researchers have combined strategies from laboratory and classroom research into programs of instruction. For example, (Melo & Miranda, 2015) used an instructional approach 4C-ID (4 Components of Instructional Design) which involved many of the strategies identified above. Specifically, they used:

- Sequenced learning tasks requiring learners to integrate and coordinate skills, accompanied by process support which they gradually withdrew;
- Supportive information – domain models, systematic approaches to problem-solving, cognitive feedback;
- Procedural information just in time; and
- Part task practice where automaticity was required.

Comparing students' performance where this model was used with that of others taught in a conventional method, the authors reported improved knowledge acquisition and transfer, less perceived cognitive load, and therefore improved learning efficiency. While at least part of the difference could also have been attributed to the digital learning environment of the experimental group (to which apparently the control group did not have access), the study is evidence of an attempt to integrate these research findings related to transfer into educational practice (Melo & Miranda, 2015).

In a different field, health education, Peters et al. (2015) investigated the effect of units of learning designed following the transfer principles of generalisation and application in multiple contexts. Specifically, they incorporated:

- reflection on the learning content and its relevance;
- personal beliefs and student choice in assignments;
- decontextualised principles; and
- applying the decontextualised principles in other contexts.

Compared to the control group with normal classroom lessons, Peters et al. (2015) found better transfer of the targeted health principles in the post-test, including in new contexts.

Although not allowing for any single factor to be pinpointed as key to transfer, these studies of learning programs are encouraging in demonstrating that combinations of factors have impacted positively on transfer.

2.7.5 Mechanisms in transfer

In contrast to the research attempting to identify strategies to be put into practice in classrooms, other researchers have focused more on models and mechanisms of how concepts are acquired and transferred. An understanding of these could support educators to choose strategies appropriate for the learners in their charge and adapt them in response to learners' needs, rather than rely on formulaic methods. This research has been strongly influenced by the social and contextual models of transfer.

Mestre (2005) distinguished between the traditional model of transfer, which asks the question: *Did transfer occur?* and what he referred to as the emerging view, which asks questions like: *What knowledge was activated in this context?*; and *What representations of context are created?* From this perspective, transfer becomes a dynamic process in which knowledge is activated in response to context. In this expanded view, transfer includes a range of knowledge pieces that may be coordinated to varying degrees, both productively and unproductively (Royer et al., 2005). Four papers by physics educators published as part of a review of transfer of learning (*Transfer of Learning from a Modern Multidisciplinary Perspective*, 2005) described transfer in terms of activating pieces of knowledge, coordinating the knowledge pieces activated and serving the purpose of making sense of a context. DiSessa and Wagner (2005) used the framework of a coordination class to interpret how knowledge is and is not coordinated by learners. Dufresne et al. (2005) and Rebello, Zollman, Allbaugh, Engelhardt, Gray, Hrepic and Itza-Ortiz (2005) emphasised the dynamic nature of the process and the focus on what students do. Students were also the centrepiece of the actor-oriented perspective outlined by Lobato (2006) and again in (Lobato, 2012). This particular model has informed research such as the study by Roorda et al. (2015), which followed students from year 10 to year 12 as they developed procedures to calculate instantaneous rate of change. They found that time was needed to acquire single procedures and considerably more time for connected repertoire. Their work also emphasised the difference in thinking between novices and experts and the role of scientific terms velocity and slope in forming a bridge for creating relationships between situations and procedures.

2.7.6 Revisiting transfer

Two more recent collections of papers on transfer were published in 2012 in special issues *of Educational Psychologist* and *Journal of the Learning Sciences*. Papers in these issues included a diverse range of perspectives on transfer, as is detailed in the introductions. Engle (2012) in the

Journal of the Learning Sciences described the expanded conceptualisation of transfer, extending the idea of what is transferred beyond concepts to include dispositions, representations, learning strategies, discourse practices, identity positioning as well as acknowledging the diverse ways in which learners use prior knowledge including as preparation for future learning. In their introduction to the *Educational Psychologist* special issue, Goldstone and Day identified three themes: the importance of the learner's perspective, the role of motivation in transfer and the existence of specific classroom strategies to optimise transfer.

Nearly a decade has passed since these collections of papers were released, and in this time, researchers seem to have taken up the challenge to investigate ways to enact research findings in classrooms. Peters et al. (2015) reported success with a curriculum consistent with transfer research findings for health with year 7 and 8 students in the Netherland; Chung, Delacruz, Dionne, Baker, Lee and Osmundson (2016) with a computer-based tutor; and Hu, Jia, Plucker and Shan (2016) with a critical thinking program. On the other hand, the success of the preschool maths intervention of Watts, Clements, Sarama, Wolfe, Spitler and Bailey (2017) was limited to short-term transfer. Taking issue with the one size fits all application of strategies supported by research evidence, Farmer (2020) proposed a more nuanced application of research findings by suggesting that researchers should work together with teachers to investigate which strategies are appropriate for particular subgroups of learners. He suggests a tiered system to align interventions with developmental factors.

Transfer research has moved away from defining what was transferred and how it was used from an expert's perspective since, unsurprisingly, transfer by this definition is rare and searching for fundamental factors that influence has yielded at best variable results. In the more expansive definition, transfer is conceived as how a learner's attempt to make sense of a context using their knowledge, skills, and dispositions acquired from past experience plays a key role in their interpreting and responding to a context. To greater or lesser degrees, transfer research now attempts to describe how learners use past learning to construct responses to new contexts and what strategies educators can use to support them to do this adaptively.

This review has detailed a considerable amount of research into the impact of a range of factors on learners' capacity to transfer concepts they have been taught. The gap to be addressed in this thesis is the translation of these findings into classroom programs that could be used in South Australian primary schools. In particular the research investigates programs constructed using strategies that are wide reaching and flexible enough to be adapted for a range of science concepts in a range of classrooms, rather than specific procedures with limited application.

2.8 Transfer Research Methods

With regards to the research question: What factors affect transfer of science concepts by South Australian primary school students? the purpose of this section is to outline the range of research methods used by transfer researchers so that the methods chosen for this study could be located in this range. Research methods used to investigate transfer typically take one of several forms depending on the view of transfer of the researchers. Key features of these are compared in Appendix E – Common Methods in Transfer of Learning Research. The traditional view or transfer corresponds to the definition of targeted transfer in Table 2-1, while the expanded view corresponds to the grounded definition.Appendix E – Common Methods in Transfer of Learning Research illustrates the considerable variation between methods in transfer research. Each of the four main types of research methodology is dealt with separately below.

2.8.1 Analysis of individual student thinking

When randomised controlled testing yielded at best variable success in identifying variables that promoted transfer, researchers taking an expanded view of transfer looked to more qualitative methods, collecting a larger quantity and variety of data from a smaller number of subjects in an attempt to follow their thinking and understand what happened in transfer situations. These commonly involved a think-aloud strategy to elicit but not influence thinking. Given that any use of learning will change that learning, even if it is just reinforced by practice in recall, the subjects thinking would have changed, but the aim was usually to keep the experimenters' influence to a minimum. Subjects in these studies were often volunteers taken from classes where the learning was being taught as part of their regular curriculum. Some followed the learners for extended periods of time, charting changes in their thinking over that time (Roorda et al., 2015). Given the closer link to their course of study and the more individual attention from the researcher, it might be expected that these subjects would have had more cognitive engagement with the task. Combined with a broader conception of what constituted transfer, studies using this methodology can measure transfer of a more diverse range of concepts and parts of concepts.

This methodology of charting changes to learners' thinking over extended periods of time, can yield a much richer set of data, but the challenge lies in interpreting it. Individual pieces of knowledge can be identified readily but measuring the degree of coordination of these in constructing the response is more difficult. One proposed solution is the coordination class (DiSessa, 2002, 2004) which describes a concept in terms of coordination of relevant knowledge pieces. In its original form, the concept was described from an expert's point of view, but DiSessa and Wagner (2005) later modified it to incorporate a level of coordinated thinking, which, although more limited than that of the experts, still works in the context. Thaden-Koch, Dufresne and Mestre (2006) adopted the term coordination system for their modified coordination class framework and used it to analyse recordings of student interviews about whether five different animations represented realistic motion. Levrini and diSessa (2008) also found variants of thinking that extended without threatening the expert coordination framework.

Other frameworks that can describe degrees of knowledge coordination include SOLO, Structure of the Observed Learning Outcome (Biggs & Collis, 1982) and DOK, Depth of Knowledge (Webb, 2002). These two frameworks have been described in Chapter 2.2.1. The two frameworks align best at the unistructural/recall and reproduction level but then diverge as SOLO follows the individual knowledge pieces and their coordination in one and then multiple contexts. The key difference between reproduction and understanding occurs in the transition from multistructural to relational thinking. With SOLO framework, quite short responses can provide evidence of quite sophisticated thinking. In addition, SOLO could be applied to thinking which does not take the same structure as that of the experts, both that which works in a limited way and misconceptions that might inhibit further learning.

DOK describes the activities of learners which demonstrate increasingly complex thought as learners coordinate increasingly more knowledge pieces at a greater level of abstraction. It is clear how each level extends that before, but harder to see how a transfer task might be framed to provide evidence of several different levels. In some ways, it is similar to Bloom's taxonomy (Anderson, 2001) in describing activities that would allow students to demonstrate the kind of thinking sought, but engaging in those activities does not guarantee they have used that thinking.

One potential solution to the problem of interpreting evidence of transfer in qualitative data might be to use SOLO to measure the extent to which the relevant parts of the causal net in a coordination class have been applied. This would cater for both expert and non-expert thinking and differentiate between different degrees of coordination.

2.8.2 Big data analysis

For educators, especially those outside of universities, information from research remained largely inaccessible, and investigation of transfer in their world came in the form of the increasing prominence of standardised testing and trialing of new materials and programs designed to improve learning outcomes. Standardised testing had been in use as a diagnostic tool for much of the 20th century. Tests of literacy; (e.g., Spelling Age (Westwood, 2005), TORCH reading comprehension (ACER, 2013), general intelligence (Roid, 2003)) had been routinely used in schools to select students for particular courses of study or styles of teaching and to diagnose learning deficits for remedial instruction. However, the introduction of national and international testing (e.g. internationally PISA and TIMSS, and within Australia NAPLAN and NAP-SL) from the late 20th century raised the stakes of these tests as potential sources of data for evaluating jurisdictions, schools and teachers. The resulting league tables of schools and “please explain” interrogations of school-based leaders and teachers have overlooked the potential of the data collected to provide insights on factors that affect transfer. As well as success in test items that require transfer of targeted learning, the tests collect a range of survey data related to demographics, dispositions and resources of the participants and hence provide the potential for analysis on how these variables correlate with transfer in the test items. ACARA, the authority responsible for the tests, prepares reports summarising results, e.g. (Kesidou, 2012) for NAP-SL, (Thompson, 2013) for PISA and (Thompson, 2012) for TIMSS, but other researchers have looked more closely for correlations between survey variables and test performance. For example, Gee and Wong (2012) used the data from PISA 2006 to investigate correlations between inquiry-based teaching practices and success in test items, and Gabriel, Signolet and Westwell (2018) looked at the interaction between learner dispositions and mathematics achievement.

Participants complete the tests individually in their school environment. The tests are compulsory and often accompanied by significant build-up from within and outside the school community. There is often behavioural engagement, potentially cognitive engagement depending on how students perceive their results will be used, and sometimes negative emotional engagement from associated stress. Those whole cohort tests that provide individual normative feedback (e.g., NAPLAN) could be expected to be associated with more cognitive engagement but also more anxiety and stress. On the other hand, sample assessments where students receive little or no individual feedback may have varying degrees of all three forms of engagement.

Because there is a preference for single correct answers scored by computer, the tests are limited to measuring transfer of the intended learning on a binary yes/no basis. Some authorities publish a sample set of test items, which offer educators the opportunity to use them with their own learners in a way that improves their understanding of what and how students transfer. Simply asking for an explanation of their choice in multiple-choice items or using an item as a basis for a class discussion can elicit a wealth of information on variation in students’ thinking.

Another variation in this big data methodology used grades collected as summative assessment for courses of study as a measure of transfer and data from surveys administered by the researcher for the independent variables. Blackwell et al. (2007) measured goal orientation and theory of intelligence of Year 7 students and looked for correlations with maths grades in Years 7 and 8. This methodology has also been used at tertiary level. Kornilova, Kornilov and Chumakova (2009) found correlations between grades and subjective measures of intelligence and achievement, while Shea, Gozza-Cohen, Uzuner, Mehta, Valtcheva, Hayes and Vickers (2011) also used final grades to correlate with the quality of learning processes in online communities of inquiry.

2.8.3 Quasi experimental design

The final methodology available to educators is designed to evaluate interventions, programs or materials designed to improve learning outcomes (as measured by transfer). Typically these programs are designed in response to an identified need for improving educational outcomes and often claim to be research-based so that in a best-case scenario, they are applying strategies that have shown promise in one of the first two types of research. Randomised controlled testing is difficult to carry out here. Students in schools are grouped in classes, forcing a quasi-experimental design and necessitating relatively large sample sizes. In addition, there may be considerable difference between teachers and schools both in the way the programs are implemented and in their attention to integrity in data collection. The complexity and unpredictability of school life mean that interruptions, missing data and variable exposure to the program are often the norm rather than the exception. For this reason, designs that attempt to control variables are often augmented by qualitative data collection in the form of student reflections in learning journals or interviews or teacher observations to yield a richer insight into what learning was activated in each situation.

In terms of the three dimensions of student engagement of Blumenfeld and Meece (1988); behavioural, emotional and cognitive, the novelty effect of the materials or programs may enhance emotional and cognitive engagement, but the challenge of being asked to think in new ways may have either a positive or negative effect on behavioural and cognitive engagement. Unlike the large scale testing methodology where the effect on engagement is difficult to measure reliably, qualitative data from student reflections can provide some insight into this. Melo and Miranda (2015) measured knowledge acquisition and transfer as well as student perception of cognitive load in evaluating their physics program, while Hackling (2008) measured learning outcomes in science literacy and science processes as well as attitudes of teachers and students in an evaluation of Primary Connections science program.

In addition, some researchers are now using a mixed-methods approach, where two or more of these methodologies are combined to address the research question (Bae & Lai, 2020). Combining qualitative and quantitative measures can yield a richer data set, with potential to compare the effectiveness of different factors and gain insight into how these factors are operating.

2.8.4 Translational research

Translational research is not a research methodology but rather an approach to research that uses research findings to benefit individuals and the community directly. The 2020/ 2021 COVID pandemic has raised the profile of medical translational research as the trial phases of COVID 19 vaccines and treatments have received widespread media attention. Even before the pandemic, translational research in medicine was well established with dedicated institutes (e.g. Translational Research Institute Australia[4]) and journals (e.g. American Journal of Translational Research). Woolf (2008) distinguished two distinct phases: the development of the drug, prevention or treatment (T1) and the trial, dissemination and uptake by the wider medical community (T2) and notes that T1 receives more attention and funding in the USA. A systematic review by Fort, Herr, Shaw, Gutzman and Starren (2017) mapped the changing use of the term translational research and unpacked the catchphrase from *bench to bedside* into five distinct phases:

- T0 laboratory research in cell or animal models;
- T1 early testing in humans;
- T2 testing effectiveness in humans and establishing clinical guidelines;
- T3 implementation and dissemination; and
- T4 investigating outcomes and effectiveness in populations.

In education, translational research as the link between research and school practice is not as well established. In a publication entitled, *From Concept to Classroom*, Mitchell (2016) outlines the following 6 phases in translational research:

- Basic science research (T0);
- Development of interventions (T1);
- Testing the effectiveness of interventions (T2);
- Translation of evidence into guidelines and policy (T3);
- Investigating the impact of an intervention in the wider population (T4); and
- Global implementation (T5).

Evidence of efforts in the first phases of the Mitchell (2016) process lies in the availability of publications like Best Evidence in Brief[5] and MESH guides[6], websites associated with universities and

---

[4] https://www.tri.edu.au/translational-research-institute-australia
[5] https://the-iee.org.uk/what-we-do/best-evidence-in-brief/
[6] http://www.meshguides.org/what-is-mesh/

which offer research findings in formats easily accessible to interested educators. The key term in the last sentence is *interested* educators. Those who take the trouble to sign up for the e-newsletters, read them, make the connection to their practice, implement them in their classrooms in a way that is faithful to the original research findings and continue this past a one-off activity may succeed in the aim of translating research into improved learning in students. To foster this continued implementation, Mitchell (2016) also points out the need for both knowledge support and decision support (stages T4-T6) in addition to the phases involved in creating classroom interventions.

Translational research is not aligned to any particular research methodology and often uses both qualitative and quantitative methods to achieve its goal of improving educational outcomes (Mitchell, 2016). Quantitative data can provide evidence of the impact of research findings on target populations and is useful in identifying conditions under which strategies are successful or need refinement. Quantitative evidence is also useful in convincing educators other than the early adopters that a strategy has merit. Qualitative evidence from both students and teachers can identify how strategies need to be refined and provide feedback to laboratory researchers on knowledge gaps that need to be researched.

One of the challenges of translational research is maintaining integrity in research methodology in the complex and unpredictable contexts of school classrooms. It means that researchers need to be agile and flexible in adapting their methods to unforeseen changes in participants and also that the generalisability of any one study beyond the group of participants may be limited. The more replications of studies from which evidence is obtained, the more convincing is the evidence.

2.9 Conclusion

Transfer of learning has been the subject of research for well over a century, and the resulting body of knowledge about transfer consists of a diverse range of definitions, taxonomies, models, theories and research findings on the impact of various factors on transfer. Given that transfer of learning is their core business, educators might ask what this body of knowledge offers to inform how their practice might optimize transfer for their students. Some relevant findings from the literature of transfer research have been set out in this literature review. For classroom teachers in primary schools, what is missing is described in these three points:

a) A set of commonly accepted definitions, taxonomies, models and theories for educators - in short, a way of thinking about transfer in the classroom;
b) Clear evidence on the impact of a range of factors on transfer - in short, some indication of what might and might not work to improve transfer; and
c) Examples of the application of these factors to primary school classrooms - in short, evidence that this applies to their circumstances in primary school classrooms.

These three points constitute the knowledge gap that this research sets out to address. Chapter 3 addresses point a) by describing how two definitions can complement each other in describing transfer. It also describes two different models of transfer and the frameworks that were developed to describe the learning content, learning and transfer tasks and how transfer is measured. Chapters 4 and 5 describe five experiments that investigated point b) and contribute examples as described in point c). Chapter 6 considers the implications of the findings of these experiments for a range of people in the education community.

3 Conceptualising transfer

3.1 Overview

The literature review suggested that at least some of the inconsistent and contradictory findings in transfer research can be attributed to the inconsistencies in the language and conceptualisation of transfer. To address this, a range of definitions, models and frameworks were developed or adapted by the researcher to provide clarity and consistency around measuring transfer of science concepts and variations in the factors which might influence this transfer. Where they have been based on the work of other researchers, this has been acknowledged. The frameworks, in particular, evolved throughout the studies, adapting to best suit the characteristics of successive data sets. These changes are described in the methods of each experiment, and the final form is presented here.

This chapter is presented in three sections:

Section 1 *Definitions of transfer*. This section clarifies two distinct perspectives on transfer used in this study to interpret evidence of transfer for different purposes.

Section 2 *Models of transfer*. This section outlines two ways of describing the transfer process, and these are used to discuss instances where transfer did and did not succeed and include factors that might affect this process.

Section 3 *Factors affecting transfer*. The frameworks constructed to describe variation in the factors identified above are presented here. These factors relate to the:

- Learning content
- Learning experience
- Learning and transfer *tasks*
- How transfer was measured

The boxes labelled *In the classroom* use the following task from one of the classroom experiments to illustrate the ideas presented in each section.

This chapter examines key aspects related to transfer of learning and how it is conceptualised in this thesis, especially in the investigations using primary (chapter 5) and secondary (chapter 4) data. Figure 3-1 is the first in a series of examples drawn from the classroom research that serve to illustrate the framework.

Figure 3-1 Into the classroom - the classroom example

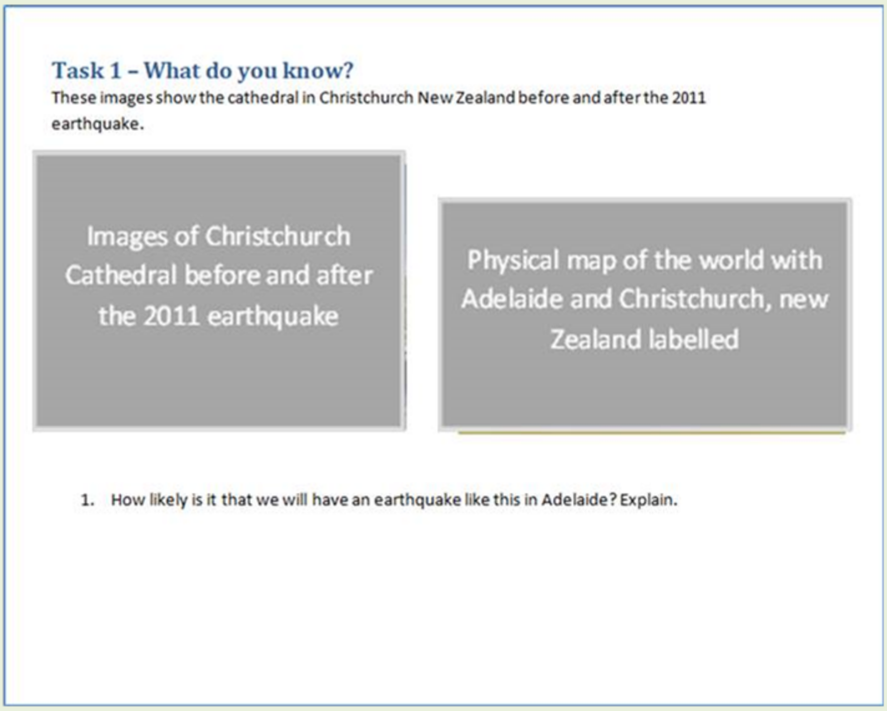
In the classroom 1 – the classroom example

The Australian Curriculum Year 6 earth sciences curriculum concept relates to sudden changes in the earth's surface.

Content description: Sudden geological changes and extreme weather events can affect the earth's surface.

Achievement standard: They explain how natural events cause rapid change to the earth's surface. (ACARA, 2021a)

The unit of learning involved in this research focused on the concept of interactions between tectonic plates to explain earthquakes. The Adelaide earthquake task below was designed to elicit students' understanding of this. The task was completed twice, once as a prior knowledge activity and once towards the end of a unit of work on earthquakes.



Task 1 – What do you know?

These images show the cathedral in Christchurch New Zealand before and after the 2011 earthquake.

Images of Christchurch Cathedral before and after the 2011 earthquake

Physical map of the world with Adelaide and Christchurch, new Zealand labelled

1. How likely is it that we will have an earthquake like this in Adelaide? Explain.

Here are three student's responses to this task:

Student 1: *You can't say- they can occur anywhere and it's just luck.*

Student 2: *Not likely because we haven't had any since I can remember.*

Student 3: *Not likely because there aren't any tectonic plates under us.*

Student 4: *Not likely because we aren't near the edge of a tectonic plate.*

Responses of students 1, 2 and 4 came from the task used to elicit prior knowledge before the teaching and that of Student 3 from the task used after participating in the learning activities.

3.2 Defining transfer

Rather than adopt one definition, this study acknowledges two ways of conceiving transfer of learning, both of which have relevance to a classroom setting. As outlined in chapter 2.2 these are:

Grounded transfer: *the activation and application of past learning to inform a response to the current situation*.

Targeted transfer: *the activation and adaptive application of curriculum concepts in non-rehearsed situations.*

These correspond to the expanded and traditional views of transfer respectively (Mestre, 2005). Acknowledging two forms of transfer has been necessary to avoid debates on what is and is not transfer and focus on what is being transferred and under what conditions. Grounded transfer includes all learning for which there is evidence and gives a rich picture for educators' formative assessment. It allows educators to target their feedback and plan the next learning steps to develop learners' capacity to transfer. On the other hand, targeted transfer is the basis of summative assessment and restricts the focus to the targeted curriculum concept. The adjective adaptive is used here to specify the application of the concept in a way that is consistent with western science. Non-rehearsed implies that students have not been previously coached in this task. Targeted transfer is thus a subset of grounded transfer used for summative assessment.

Figure 3-2 interprets these definitions adopted in this study in the context of the classroom task described in Figure 3-1.

Figure 3-2 Into the classroom 2 - definitions of transfer

In the classroom 2 – definitions of transfer

This table compares the two definitions of transfer using the Adelaide earthquake task.

Definition source	What is transferred	Behaviour (what they do with it)	Contexts (Where and when)	Similarity/ difference	Application for educators
Targeted (Cognitive science)	concept of interacting tectonic plates	explain observations of the distribution of severe earthquakes	any evidence of an earthquake or location in relation to tectonic plate boundaries	non-rehearsed	To what extent can they demonstrate transfer of the tectonic plates concept to explain earthquake incidence?
Grounded (Socio-environmental	range of ideas that might explain the distribution of earthquakes, including some misconceptions and some general knowledge or limited ideas about tectonic plates	Suggest explanations for the distribution of severe earthquakes	any evidence of an earthquake or location in relation to tectonic plate boundaries	prior/current	What do they bring to explain earthquake incidence?

Student 4 from *In the Classroom 1* shows ***targeted transfer*** –the targeted science concept was the relationship between severe earthquakes and the boundaries of tectonic plates. Although the other three students do not demonstrate targeted transfer, from a ***grounded transfer*** perspective, they show transfer of a range of general knowledge and misconceptions, including some about the targeted science concept. This indicates to the teacher what each student needs to work on.

As well as the term transfer, some other terms are used in inconsistent ways in transfer research.

The use of these in this study is clarified in the glossary.

3.3 Modelling transfer

The two definitions differ in the breadth of learning considered transfer, with targeted transfer having a much narrower focus. The two models below differ in the perspective they take on the transfer process, with the two-step view focusing on the learning content with the learner as a vehicle and the more recent view focusing on the learner operating in the landscape of the learning content. The dumbbell diagram shown in **Error! Reference source not found.** is my representation of he two-step view of transfer.

Figure 3-3 Two-step model of transfer

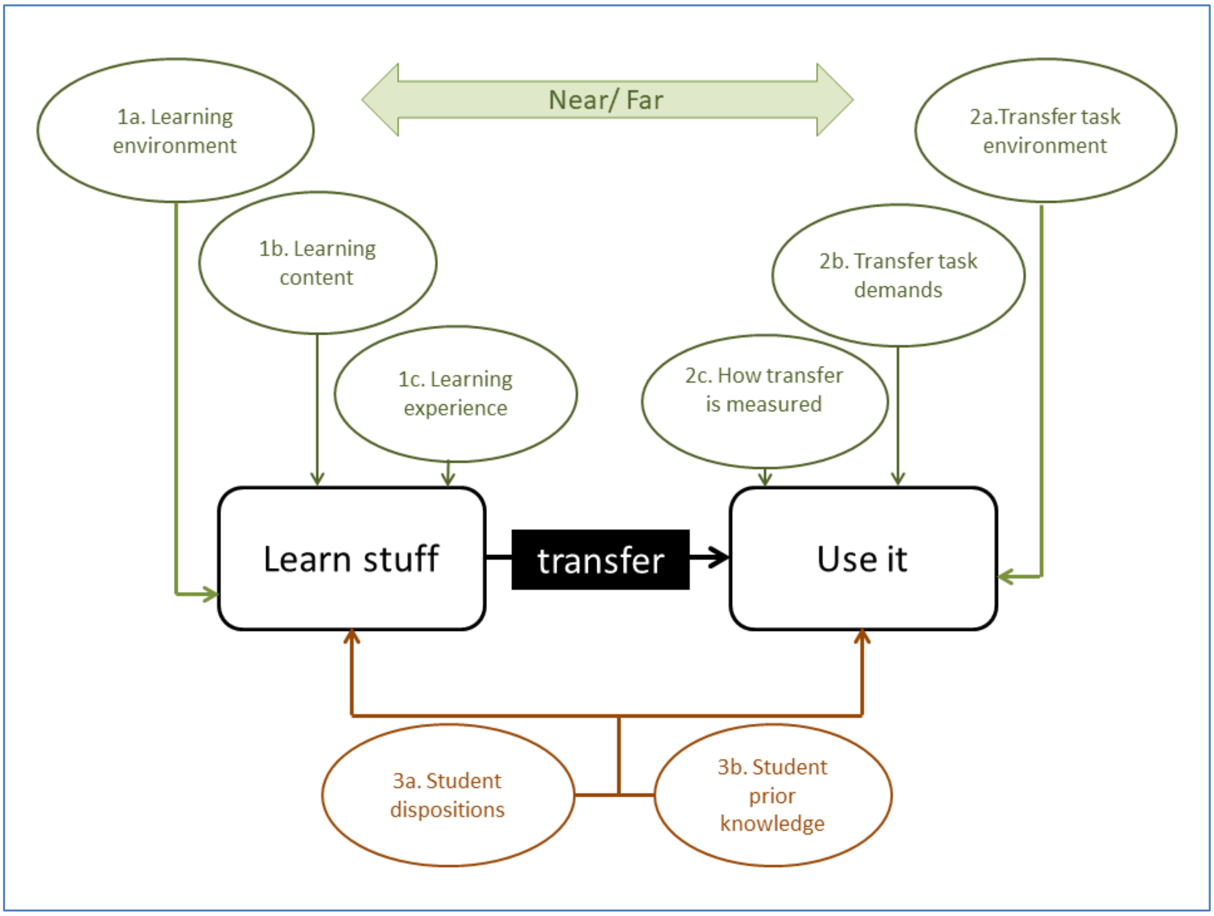
In this model:

- *learn* refers to the act of acquiring additional mental resources;
- *stuff* refers to the mental resources acquired. Here it is kept deliberately non-specific to acknowledge the wide range of concepts, processes, dispositions etc. that might be acquired; and
- *use* refers to the application of these resources to contribute to a response in other situations, making them visible to educators or researchers.

This model is elaborated on to outline extra information about factors that might affect either the learning experience or the using, represented by the bubbles in **Error! Reference source not found.**. his diagram is used throughout the rest of the thesis as a vehicle to explore the groups of factors affecting transfer of learning.

Figure 3-4 Some factors affecting transfer of learning.

(Factors in the green bubbles relate to the learning or transfer situations, while factors in the brown bubbles are attributes of the students.)

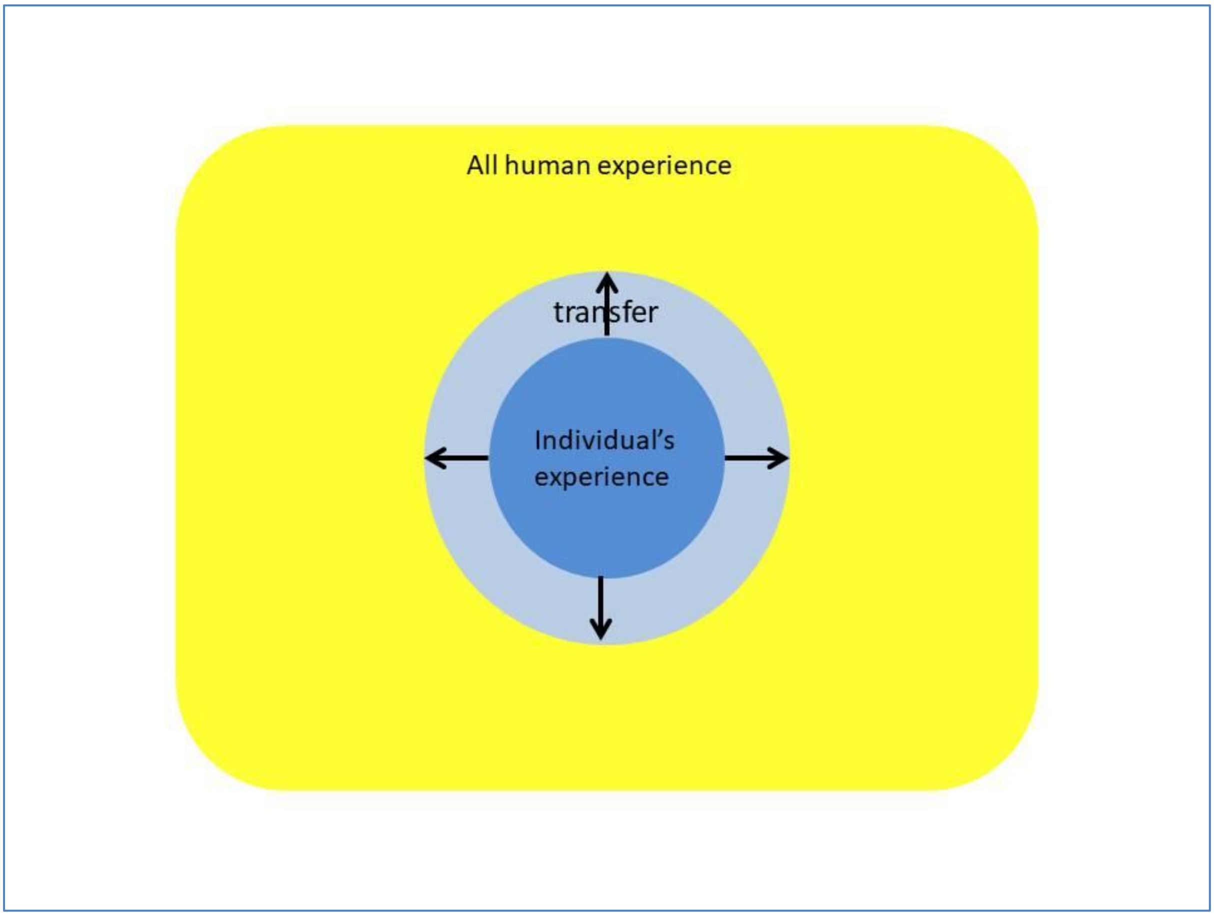


The three groups of factors described in this diagram are those related to the learning experiences (1a, 1b and 1c), the transfer task (2a, 2b and 2c) and the learners themselves (3a and 3b). The range of factors related to learning experiences includes pedagogy and learning activities, which directly affect the cognitive resources acquired, while the demands of the transfer task affect the response constructed by the learner. Environmental conditions, both physical and social, affect both the acquisition of cognitive resources and their use to construct a response to a transfer task. The differences between the conditions of the learning experience and those of the transfer task are associated with near transfer when the two situations are similar or far transfer when there are substantial differences between them. These two groups are factors which educators (in the broadest definition of educators, including curriculum and assessment personnel) can directly influence and about which students are often more passive. However, because transfer occurs in people's minds rather than in test tubes, factors of the learners have been acknowledged in bubbles 3a and 3b. These factors, which students bring with them, are less accessible to educators and affect both learning and transfer tasks.

In this model, time passes from left to right with the acquisition of cognitive resources preceding their use in constructing a response. The role of educators is to engineer learning experiences involving curriculum concepts and so develop students' capacity to respond adaptively in a range of transfer tasks. This is a snapshot of a bigger picture in which there are many iterations of this process. Each experience of transfer in producing a response to a task changes the cognitive resources available for the next one. Learning is an iterative process.

An alternative view of transfer as the generalisation of experience is shown in the concentric circle diagram in **Error! Reference source not found.**.

Figure 3-5 Generalisation model of transfer



This generalisation model represents all possible human experience as the large yellow rectangle, while the smaller, darker blue circle represents a single individual's experience. Transfer is the extension of the individual's experience to include other parts of human experience. The model works like a feeding amoeba as the individual's existing experience engulfs instances outside their current experience so that they are added to their repertoire of experience. Here the role of educators is to offer experiences that allow students to extend their current experience adaptively.

Absent from these models is any indication of the mechanism of transfer - what is happening between the learning and the using of concepts (the black box of the two-process model) or between the limited and expanded experience (the four black arrows which enlarge the circle in the generalisation model). Any attempt to describe this mechanism of transfer will need to account for:

- which aspects of the transfer task the student attends to;
- the connection made by the student between the aspects attended to and some existing mental resources. This connection could be relatively automatic or the result of a deliberate search;
- application of the mental resources to the task to produce a potential response. This application may be a straightforward use of a previously learnt process or an adaption or combination of processes to work in this context; and
- an evaluation of whether the resulting response is fit for purpose. The outcome of this evaluation will depend not only on whether it satisfies the prompt but also on the significance placed on the response.

Of the models reviewed earlier, the sense-making model of Nokes-Malach and Mestre (2013) comes closest to this. The Nokes-Malach and Mestre model emphasises the construction of a representation of the task in laying the foundations for transfer and the process of evaluation running alongside each step as sense-making. The actual transfer mechanism is outsourced to other researcher perspectives, e.g. identical rules, analogy, constraint violation.

Figure 3-6 Into the classroom3 - models of transfer

In the classroom 3 – models of transfer

In the two-step model, the stuff learnt was the concept of tectonic plates and its application in explaining and predicting the occurrence of severe earthquakes. For Students 1, 2 and 4, the conditions of this learning are not known since it was acquired before the concept was addressed in the classroom. For Student 3, it was acquired in a science classroom using tell and practice pedagogy. The learning was used to produce a written response to the Adelaide earthquake task for all students.

With the generalisation of experience model, the Adelaide earthquake task offered all students the opportunity to transfer their understanding of the causes of earthquakes by comparing the likelihood of a severe earthquake in Adelaide with that of one in Christchurch, New Zealand. Only Students 3 and 4 accessed the concept of tectonic plates as part of their mental resources and were able to do this. Students 1 and 2 provided no evidence of the tectonic plates concept and drew on other aspects of their experience. There are several possibilities: they did not have this concept, they had it but did not invoke it, or it was invoked but did not get past their internal evaluation process to make it to the response.

3.4 Factors affecting transfer of learning

The research question aimed to investigate factors affecting transfer of learning, and groups of these factors have been set out in **Error! Reference source not found.**. Several frameworks describing ariation within them were developed to describe and compare transfer in the classroom experiments. Descriptions of these follow here.

3.4.1 Learning content

For this study, the learning content to be transferred is science concepts. The following framework was simplified from the coordination class described by DiSessa and Wagner (2005) to identify which aspects of these concepts were transferred.

Using the idea of a concept consisting of coordinated knowledge pieces, these pieces may be:

Strategic: related to when, where and why to apply the concept (including the core function, span and alignment of DisSessa's coordination class);

Functional: how to apply the concept, including what to read out of the context and how the rules and patterns work (including readout and causal net from the coordination class framework).

One factor investigated in the classroom research in chapter 5 was whether teaching the strategic aspects as well as the functional aspects would improve transfer. The hypothesis was that students lacking strategic aspects will struggle to apply the concept unprompted, while those lacking functional aspects might recognise that the concept would be useful but struggle to apply it accurately in the task context. The concept outline framework was developed to identify and describe the knowledge pieces of a concept, and it is shown in Figure 3-7 with the tectonic plate concept at Year 6 level as an example.

Figure 3-7 Into the classroom 4 - describing learning content

In the classroom 4 – describing learning content Tectonic plates and earthquakes at year 6 level		
Concept Outline		
Strategic knowledge	What is it for? (core function)	To explain why severe earthquakes occur more often in some locations than others or to predict whether or not they might occur in a particular location.
	Where can you use it? (span and alignment)	Wherever there is a need to explain or predict the occurrence of severe earthquakes. It is not enough by itself to account for some less severe earthquakes.
Functional knowledge	What do you need to find? (readout)	Evidence of a severe earthquake or reference to tectonic plate(s)
	How does it work? (causal net)	Severe earthquakes can occur where two moving plates collide or grind past each other. Away from the edges of the plates, severe earthquakes are much less common, although less severe ones may happen. There are maps of the world marking out the plate boundaries and locations of severe earthquakes.

The responses described in *Into the Classroom 1* from students 1 and 2 show no evidence of transfer of strategic aspects, and the lack of this precluded any functional transfer they might have had as the task did not cue the concept.

The response from Student 3 shows evidence of strategic transfer in that they invoked the tectonic plates concept, but the functional transfer used a faulty causal net.

The response from Student 4 shows evidence of both strategic and functional transfer of an adaptive causal net.

The idea that transfer of learning could be improved by teaching information beyond the functional level was suggested by (van Gog, Paas, & van Merriënboer, 2004), in the context of enhancing problem solving. Although acknowledging the extra cognitive load involved, they suggested that showing students why and how experts chose solution strategies could enhance their problem solving ability.

3.4.2 The learning experience

A learning experience engineered by teachers (or researchers) may contain these three parts:

- Access to the targeted information or knowledge
- Opportunity to practice reproducing, re-representing or applying that knowledge
- Access to feedback on how successful their efforts were

There is considerable variation in how these parts are managed. In this study, the high challenge pedagogy differed from the low challenge by offering students the opportunity to apply or invent the knowledge before giving them access to the targeted science version (productive struggle) and including information about the potential use of the targeted learning in their future education or real-world contexts.

Figure 3-8 Into the classroom 5 - describing the learning experience

In the classroom 5 – describing the learning experience

The learning experiences associated with the Adelaide earthquake task were part of an experiment described in the next section. A tell and practice pedagogy was used with information about the targeted concept delivered by video, and students then had opportunities to practise using this in a variety of tasks. Self and peer assessment activities were included, but there was no feedback from the teacher or researcher.

3.4.3 Learning and transfer tasks

In this thesis, a task is an activity that students are asked to do to engage with the learning. Debates about whether the task is a learning or assessment task are not entertained here. Firstly all tasks are learning tasks because participating in them changes the student's brain, although not necessarily in ways that we as educators might intend. Secondly, all tasks are assessment opportunities, whether or not educators or students decide to take up the opportunity.

To describe and compare tasks in this thesis, I have developed a framework where tasks are seen as having three parts:

- ***task context*** – the setting of the task, which may be presented by verbal descriptions, images, concrete materials or any combinations of these. Here this is limited to aspects of the task itself. It is different to the task environment which refers to the physical and social conditions as well as the authority under which student particpate as described by Barnett and Ceci (2002);

- ***task prompt,*** which sets out the response required of students. The prompt requires students to activate past learning, apply it to the current context and process it in a particular way. The response may be communicated in writing, orally, individually or as a group or in some cases not communicated at all, but there is still a direction to engage with the context in a particular way (a context without a prompt is free play); and
- ***solution path*** is the process that a student goes through to generate the response (Nokes-Malach & Mestre, 2013). Although this is sometimes scaffolded, in problem-solving it is left to the student to generate their own solution paths, which for novices is an effortful and time-consuming process when compared to the efficient strategies used by experts (DiSessa & Wagner, 2005).

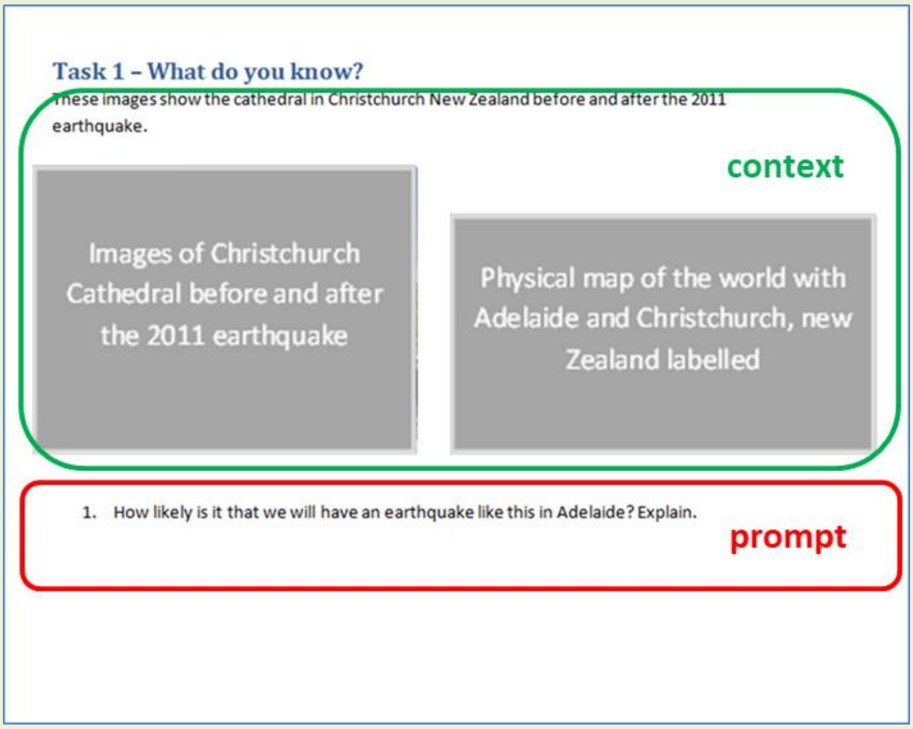
Figure 3-9 Into the classroom 7 - task components

In the classroom 6 – task components

In the task shown in the box below, the ***task context*** is outlined in green and includes the map, image and reference to the 2011 earthquake in New Zealand.

The ***task prompt*** is outlined in red. IT requires an estimation of the likelihood of a severe earthquake in Adelaide and an explanation for the estimation.

The expert version of the ***solution path*** requires students to invoke the concept that earthquakes are associated with tectonic plate boundaries. Then they can either explain that an earthquake is unlikely because Adelaide is not near the edge of a tectonic plate or that they do not have enough information to answer because they do not know where the tectonic plate boundaries are.



The framework shown in Table 3-1 was developed to map the difficulty of a task so that tasks that students did and did not transfer on could be compared. For each part of the task, two features have been described in terms of increasing intellectual demand. Some of these are based on research findings and some on classroom experience, as described in the notes below.

Table 3-1 Task difficulty matrix

Task challenge		Increasing intellectual demand →		
Context	Complexity[a]	Simplified real world	More detail → Less detail →	Real-world Abstract
	Familiarity[b]	Rehearsed They have done this before	Familiar They have experienced this context but not with this learning	Unfamiliar They have not experienced this context
Prompt	Support[c]	Scaffolded	Cued	Learner selected
	Accountability[d]	None Solution only	Elaborate Explain this answer	Consider alternatives Compare, Justify, Evaluate
Solution path	Demand[e]	Reproduce an answer	Apply a known process to get an answer	Invent a strategy to get an answer
	Learning required[f]	Target concept only	Integrate near concepts Target concept + other learning area concepts	Integrate far concepts Target concepts + concepts from other learning areas

Notes

a. The amount of detail in the context can be changed by removing detail, so the task becomes abstract or adding detail to resemble the real world more closely. Both of these have been shown to decrease transfer (Day et al., 2015; Jaakkola & Veermans, 2018; Kaminski et al., 2013). Various researchers also refer to distracting detail (Goetz & Sadoski, 1995), seductive detail (Abercrombie, Hushman, & Carbonneau, 2019)or desirable difficulties (Kachergis, Rhodes, & Gureckis, 2017) as increasing the degree of difficulty of transfer. Seductive and distracting details refer specifically to the information in the context and typically include information about non-relevant parts of the context. Desirable difficulties however may also include productive struggle, ill-defined problems and other aspects of the prompt that might interfere with transfer.

b. Increasing students' familiarity with the task by using familiar contexts or rehearsing the prompt in the context could be expected to decrease the cognitive load and support transfer.

c. Cuing removes the need for students to use strategic aspects of the task, and scaffolding removes the need to construct their own solution path. Both of these should increase transfer for this task, although they may hinder transfer on future tasks where cuing and scaffolding are not available. Cuing, in the form of hints or directions to learners, is one of the main reasons why Detterman (1993) discounted most research that claimed to demonstrate transfer.
d. The need to explain and compare solution paths makes it much harder for students to rely on reproducing previously learned causal nets as these would need to be adapted to the current context. The added demand of explaining calls for transfer of a more sophisticated causal net. In SOLO, reproducing previously learnt causal nets is recognised as level reduction, and rated as multistructural rather than its apparent relational level (J. Pegg, personal communication, March 19, 2014).
e. Barnett and Ceci (2002) described the memory demand component of transfer on a scale from execute only to recall, recognise and execute. In the framework above, this is included in support (line 3) and demand refers to the amount of cognitive effort required to apply functional knowledge and produce a response. If previously learnt material has been memorized well, reproducing it will require little cognitive demand. Likewise, applying a causal net where the readout is straightforward should also be relatively easy. However, the cognitive load is substantially increased when the student has to invent a solution path by an effortful search through prior knowledge and using trial and error to check (DiSessa & Wagner, 2005). On the other hand, if the material has not been memorised, the student may have to invent a solution path.
f. The final category references the difficulty referred to in Chapter 2.6, where students fail to transfer when the targeted learning is only a contribution rather than the sole focus of the task (necessary but not sufficient). Transfer is more likely if the learning is both necessary and sufficient.

Figure 3-10 Into the classroom 7 - task degree of difficulty

In the classroom 7 – task degree of difficulty

The earthquake task used above has been rated using this matrix.

Task challenge		Increasing intellectual demand→		
Context	Complexity[1]	Simplified real world	More detail → Less detail→	Real world Abstract
	Familiarity[2]	Rehearsed They've done this before	Familiar They've experienced this context but not with this learning	Unfamiliar They haven't experienced this context
Prompt	Support[3]	Scaffolded	Cued	Learner selected
	Accountability[4]	None Solution only	Elaborate Explain this answer	Consider alternatives Compare, Justify, Evaluate
Solution path	Demand[5]	Reproduce an answer	Apply a known process to get an answer	Invent a strategy to get an answer
	Learning required[6]	Target concept only	Integrate near concepts Target concept + other learning area concepts	Integrate far concepts Target concepts + concepts from other learning areas

Notes:

1. The context is simplified real world since only information necessary to illustrate a severe earthquake and locate the two cities has been supplied.

2. Given that the students who completed this task lived in Adelaide, we can expect that at least Adelaide and probably New Zealand were familiar; although it is unlikely the relative earthquake likelihood will have been rehearsed.

3. The tectonic plate concept was not cued by the context or the prompt, requiring students to use strategic knowledge to identify it as relevant.

4. The task requires an explanation and a comparison, allowing learners to demonstrate a connection between locations on plate boundaries and severe earthquakes compared with locations away from plate boundaries. This explanation increases the cognitive demand.

5. With the possible exception of students who have arrived from New Zealand after the 2011 earthquake, it is unlikely that students would be reproducing a memorised causal net.

6. The tectonic plate concept was both necessary and sufficient to answer this question.

3.4.4 How transfer is measured

When teachers set tasks for their students to engage with the targeted learning, they have the opportunity to collect information on the degree to which they have mastered the targeted learning. Students' responses can be assessed in two different ways:

- how well they have responded to the prompt (answered the question)
- how well they have demonstrated the targeted learning.

Sometimes these criteria are the same, but other times this is not the case, and a mismatch between teachers and students' perceptions of the purpose of the task may cause frustration on both sides. For example, in a task from the research unit, students were given a fake news report about a predicted earthquake and asked what information they would seek to decide if it was fake news. Those who went to great trouble to determine the authenticity and qualifications of the expert cited and his institution may have answered the question well but failed to demonstrate understanding of the concept of plate tectonics. For them, the tectonic plate concept was not necessary to produce a response. Typically most questions set by teachers are invitations to demonstrate learning of targeted concepts, and students who do well learn to read which concepts are being targeted. Interdisciplinary tasks that require students to integrate learning from several curriculum areas are less commonly set for students.

Targeted transfer (or learning) is commonly assessed by giving students several short tasks (or test questions) of varying degrees of difficulty and counting the number in which their response showed successful transfer of the targeted concept. The more questions asked, the higher the chance that one question will cue the learning for the remainder and remove the opportunity to demonstrate strategic transfer. To map grounded transfer a framework was developed that covered the range of responses generated by students.

This framework shown in Table 3-2 was developed to describe evidence of transfer by considering student responses to the Adelaide earthquake task, which was used twice – once as a pre-test to establish prior knowledge and again as a summative assessment towards the end of the unit. The process for developing it is described in detail in Appendix F.

Table 3-2 Framework for mapping grounded transfer in student responses

Grounded transfer categories			
Code	Evidence of thinking	Response	Example relating to the task from *In the classroom 1*
NO	None	No new thinking – no response or reproduces given information	Blank or *I don't know*
NN	Relevant but not targeting the conceptual thread	Invokes other learning related to the task but not the target conceptual thread	*It's just mother nature* *It depends how strong the buildings are*
GL	Limited general knowledge	Either names or describes or misconceptions about a related general knowledge idea	*It's not likely because we are a bigger country*
GT	Sound general knowledge	General knowledge idea relevant to and consistent with the targeted science concept	*It's not likely because we haven't had any big earthquakes here in the past*
SL	Limited knowledge about the science concept	Either names, describes or relates misconceptions about a related general knowledge idea	*It's not likely because we don't have any plates here and they have lots over in New Zealand*
ST	Sound knowledge of the science concept	Knowledge of parts of the targeted science concept and possibly the connections between them	*Unlikely because we aren't on the edge of a tectonic plate where earthquakes occur more often*

The framework allows classification of the range of learning transferred in both the pre-test and post-test versions of the task. It distinguishes between misconceptions (SL) and adaptive learning of the science concept (ST), between irrelevant (NN), every day (GL and GT) and science (SL and ST) conceptual threads and within a thread between thinking at different levels (GL/GT and SL/ST). It provides a snapshot of learners thinking (albeit through the proxy of a work sample from a task) and allows tracking of the thinking of individual learners through the sequence of learning tasks.

Figure 3-11 Into the classroom 8 - measuring transfer

In the classroom 8 – measuring transfer

The student responses described in *In the classroom 1* are examples of the following levels:

Student 1: *You can't say- they can occur anywhere and it's just luck.* (NN) not addressing the targeted science concept or relevant general knowledge

Student 2: *Not likely because we haven't had any since I can remember.* (GT) sound general knowledge (severe earthquakes are more likely where there is a history of severe earthquakes) but not addressing the targeted science concept

Student 3: *Not likely because there aren't any tectonic plates under us.* (SL) invokes the targeted concept but applies it with a misconception or faulty causal net

Student 4: *not likely because we aren't near the edge of a tectonic plate.* (ST) invokes the targeted concept and applies it with a sound causal net at Year 6 level

3.4.5 Task environment

In this thesis the term *task environment* is used to refer to a range of social and environmental aspects of the circumstances in which a task is carried out. Within the idea of task environment, the term *context has* been used frequently and quite variably by transfer researchers. In some cases, it is synonymous with the task environment, but it could also relate to the students, or the learning area of the research, e.g. this research is done in the context of science learning by upper primary students. In this study, context refers to task context as described above.

Figure 3-12 Into the classroom 10 - task environment

In the classroom 9 – task environment

This task was conducted in 7 different classrooms for this research, and the task environment could be expected to differ between them. As well as the usual chairs, tables and writing equipment, the physical environment of a classroom might include learning resources such as posters on the wall, materials and models and work samples. The social environment would have included peers, with most classes organised into table groups. Also included here are the expectations about the purpose and significance of engaging with the tasks. The instructions for teachers were to frame both tasks as part of the normal school curriculum, which means there would have been the usual school expectation that the tasks in this class were to be completed to the best of their ability. The tasks were given in science lessons, which would also convey an expectation of the type of response expected.

3.5 Evidence of engagement

The majority of tasks offered students an opportunity to give feedback on the task to the researcher. Over the two units, 69% of students gave feedback at least once and on average, students gave feedback nearly 50% of the time.

Feedback was used as a proxy for engagement. Student responses were sorted into categories, and these categories were sorted according to the engagement framework of Fredricks et al. (2004). These categories are similar to those used by Bae and Lai (2020), except that as almost no feedback addressed the social category, it was not included. The cognitive engagement category was further divided into task-oriented and concept-oriented feedback depending on what the feedback addressed. Within the concept-oriented category, some described their performance and others their learning about the concept. These are described in Table 3-3. The frequency refers to the percentage of instances of this feedback out of all feedback opportunities. The column does not add up to 100% because some students gave feedback from multiple categories in one task.

Table 3-3 Framework for assessing engagement from feedback comments

Engagement category	Subcategories	Description
Behavioural		acknowledges the box e.g. *Yes, no*
Emotional		Describes an emotional connection to the task
	generic	Non-specific, brief response e.g. *It was ok*
	positive	Positive affective response e.g. *It was fun, it was interesting*
	negative	Negative affective response e.g. *It was boring*
Cognitive	Task	Describes their experience of the task
	Task generic	Non-specific comment on task e.g. *It was OK/ good*
	Task challenge	Comment on degree of difficulty e.g. *It was easy/ hard*
	Task clarity	Comment on how easy task instructions were to follow e.g. *It was clear/confusing*
	Task suggestions	Suggestion or request for future tasks e.g. *We should do more hands on*
Cognitive	Concept	Addresses the targeted concept
	Concept performance	Self-evaluation of their own response e.g. *I did a good job of answering the questions. My work isn't very good.*
	Concept	Self evaluation of their own learning e.g. *I learnt about … I didn't learn anything*

These frameworks have been used to design and interpret the classroom experiments described in the next section.

4 Current evidence of transfer in classrooms

4.1 Overview

After positioning transfer of learning as a fundamental aspect of education, reviewing the literature on transfer research for what it has to offer educators and establishing a theoretical framework to describe transfer in classrooms, this part of the thesis takes a classroom-based approach to investigate factors that affect transfer by primary school students. The literature review identified a range of factors influencing the transfer of science concepts, and the experiments reported in this part aimed to investigate the degree to which these factors affected transfer both individually and in combination. The studies reported in this chapter involved students in the first 8 years of schooling (Reception year to year 7 in South Australia) although the majority were in Years 5 and 6, the final years of their primary schooling[7]. As part of their transition to high school, they need to transfer concepts learnt in primary school to a very different high school environment. This study thus describes what they were able to transfer before this transition.

This research is translational in that it seeks to apply research findings from laboratories in classroom situations. Its purpose was to provide research findings that primary school classroom teachers could use to better develop their students' capacity to transfer science concepts in a range of circumstances. The research was carried out in schools, by an educator, with educators and for educators and their students. In keeping with translational research, it also sought to engage the education community by seeking feedback from and sharing findings with the teachers and students involved to maximise the impact on teachers in general.

The research is pragmatic in approach. It was driven firstly by the purpose of the research to inform educators' practice and secondly by the available resources and constraints. These resources and constraints include physical (access to artefacts which might provide evidence of transfer), human (nature of the research participants and the skills of the researcher), organisational (mandated curriculum, pedagogy and school requirements) and ethical (conditions designed to minimise harm to participants, as detailed by ethics approval). In addition, it involved an iterative process as findings from the early investigations informed the methods of subsequent investigations. Invariably, despite initial planning, the process evolved over throughout the research as unforeseen challenges and opportunities arose. These challenges arose at all levels, from the rewriting of materials when the teachers who volunteered to participate happened to teach classes at different year levels to those

[7] At the time of data collection, year 7 was the final year of primary school in South Australia. In 2022 this changed to year 6.

anticipated, to the ongoing revision of frameworks to measure transfer to reflect better the data generated. Like all communities, classrooms are complex and changing, and research needs to be agile enough to cope with this while minimising compromise to the findings' reliability, validity and generalisability.

A range of qualitative and quantitative methods was employed in different phases. The three sections in this chapter use qualitative methods to examine evidence of transfer in existing classroom artefacts and identify some factors that may affect transfer. The additional purpose of these three studies was to inform the development of tools (questions and frameworks) used to measure transfer in the studies to come.

These sections investigate transfer of science concepts by primary school students, predominately in Years 4 to 6, in two different situations – standardised testing and a classroom task. They are presented as follows:

Transfer of learning in standardised testing. Data sets from two different standardised tests, National Assessment Program Science Literacy (NA-SL) for Year 6 and Trends in International Mathematics and Science Study (TIMSS) for Year 4, were available, and a qualitative analysis identified factors relating to the transfer task and the concept to be transferred as potentially affecting the demonstration of targeted demonstrated.

Transfer of learning in a classroom task. A separate data set consisted of a set of responses to a task involving a burning candle by students in Year 5 in a single school. Qualitative analysis of grounded transfer in this data set further elaborated on factors related to the transfer task and the concept to be transferred.

Transfer of learning in a classroom by primary school students at different year levels. In addition to the responses for Year 5 students analysed in section 2, responses were available for similar tasks for students from years Reception to Year 7 in the same school. Qualitative analysis of grounded transfer in this data set further elaborated on factors related to the transfer task and the concept to be transferred and added factors related to the students' developmental stage.

Together they provide evidence of both targeted and grounded transfer by primary school students and suggest some factors that may affect this.

4.2 Transfer in standardised testing

4.2.1 Introduction

National and international standardised tests such as National Assessment Program Literacy and Numeracy (NAPLAN) and Program for International Student Assessment (PISA) are a much-publicised source of data about how well students transfer learning, and not just in science. At least annually, media report data on school students' literacy and numeracy from national and international tests, usually associated with comparisons between year level cohorts, states and countries. As well as providing league tables, data from these tests inform decisions about funding and the direction and emphasis of pedagogy that directly affect students' classroom experiences.

While standardised science tests results do not have as high a profile as those of literacy and numeracy, large data sets on transfer of science concepts by students in Years 4 to 6 are collected in national and international sample assessments like National Assessment Program Scientific Literacy (NAP-SL), Trends in International Maths and Science Study (TIMSS) and more recently (progressive Achievement Tests Science (PAT science). Until 2012, NAP-SL published a subset of their questions along with the marking scheme and national percentage correct for interested teachers to use with their own students. The most recent version is the 2012 public release material (Kesidou, Sadeghi, & Marosszeky, 2013). After 2012 the test was moved online with limited information available for teachers to use with students. TIMSS publish similar information (International Association for the Evaluation of Educational Achievement (IAC), 2013).

This section uses the classifications and models of transfer to document evidence of transfer of science concepts in upper primary students in NAP-SL 2012 and TIMSS 2011 sample assessments. The question it seeks to answer is: *What are they currently transferring?* The findings informed the design of classroom strategies to improve transfer and allow the choice of strategies to target particular issues with transfer.

4.2.2 Standardised tests used

NAP-SL 2012 and TIMSS 2011 were administered as pencil and paper tests to randomly selected classes across Australia. The 2012 sample sizes were NAP-SL 13,236 students and TIMSS 6,146. The contexts are described in text with some use of diagrams and monochromatic photographs. Students respond without collaborating with peers by either identifying one or more correct answers from the 4 or 5 provided or constructing a response of between one word and a sentence (multiple-choice or short answer). PAT science has a similar format but is delivered online to students whose schools opt to participate. PAT science has no publicly available material and was not examined in this study.

4.2.3 Describing the learning

The learning content chosen for this section and sections 2, 3 and 4 was states of matter, which appears in the Australian Curriculum: Science at Year 5 level. States of matter was chosen from the other concepts as a range of classroom artefacts addressing this concept were available. Along with the relevant parts of the Australian Curriculum, the concept is described in Table 4-1 (after (DiSessa & Sherin, 1998) at Year 5 level. The description in Table 4-1 represents what Bransford and Schwartz (1999) describe as an expert's view of the knowledge required at this level or the Class A transfer of DiSessa and Wagner (2005).

Table 4-1 Curriculum details and Concept Outline of states of matter concept at year 5 level.

<table>
<tr><th colspan="3">Australian Curriculum: Science details</th></tr>
<tr><td colspan="2">Year Level Description</td><td>They broaden their classification of matter to include gases</td></tr>
<tr><td colspan="2">Science Understanding Strand
Chemical Sciences Sub-strand
Content description</td><td>Solids, liquids and gases have different observable properties and behave in different ways.</td></tr>
<tr><td colspan="2">Achievement Standard</td><td>Students classify substances according to their observable properties and behaviours.</td></tr>
<tr><th colspan="3">Concept Outline</th></tr>
<tr><td rowspan="2">Strategic knowledge</td><td>What is it for?
(core function)</td><td>Explain and predict the behaviour of materials, specifically gases</td></tr>
<tr><td>Where can you use it?
(span and alignment)</td><td>Use where ever properties of shape, volume, flow are relevant</td></tr>
<tr><td rowspan="2">Functional knowledge</td><td>What do you need to find?
(readout)</td><td>Instances of solids, liquids, gases or associated properties</td></tr>
<tr><td>How does it work?
(causal net)</td><td>Solids, liquids and gases have different properties.
<table><tr><th></th><th>solid</th><th>liquid</th><th>gas</th></tr><tr><td>volume</td><td>fixed</td><td>fixed</td><td>not fixed</td></tr><tr><td>shape</td><td>fixed</td><td>not fixed</td><td>not fixed</td></tr><tr><td>behaviour</td><td>no</td><td>flow</td><td>diffuse</td></tr></table>
Materials change between states by addition or removal of heat
These properties and changes can be explained using particle theory.</td></tr>
</table>

Both NAP-SL and TIMSS contained items that involved this concept. Although Australian Curriculum: Science focuses on the properties and behaviour part of the causal net, in 2011/2012, three of the six items involved a change of state. The items involved are unpacked separately below.

4.2.4 Transfer in NAP-SL

For NAP-SL 2012, two questions were relevant to liquids and gases, both involving evaporation as a change of state. These are shown in **Error! Reference source not found.**.

Figure 4-1 States of matter questions from NAP-SL 2012.

(Questions reproduced from (Kesidou et al., 2013).)

Image removed for copyright reasons. Original can be viewed online at

https://www.nap.edu.au/_resources/NAP-SL_2012_School_Release_Materials.pdf (page 88)

4.2.4.1 Question 21 task and affordances

Question 21 is analysed using the task framework in Table 4-2.

Table 4-2 Analysis of NAP-SL 2012 Question 21 using task framework

<table>
<tr><th colspan="4">Task analysis</th></tr>
<tr><td>Task challenge</td><td colspan="3">Increasing intellectual demand→</td></tr>
<tr><td rowspan="4">Context

Image removed – see fig 4-1

Recount of an observation by a named actor in a situation likely to be familiar or at least accessible to Year 6 students (44 words, 4 sentences, including 1 compound sentence). The idea of evaporation is primed.</td><td colspan="3">Complexity</td></tr>
<tr><td>Simplified real world</td><td>More detail →
Less detail→</td><td>Real-world
Abstract</td></tr>
<tr><td colspan="3">Familiarity</td></tr>
<tr><td>Rehearsed
They have done this before</td><td>Familiar
They have experienced this context but not with this learning</td><td>Unfamiliar
They have not experienced this context</td></tr>
<tr><td rowspan="4">Prompt

Image removed – see fig 4-1

Cloze exercise[8] requiring students to supply before and after terms for change of state.</td><td colspan="3">Support</td></tr>
<tr><td>Scaffolded</td><td>Cued</td><td>Learner selected</td></tr>
<tr><td colspan="3">Accountability</td></tr>
<tr><td>None
Solution only</td><td>Elaborate
Explain this answer</td><td>Consider alternatives
Compare, Justify, Evaluate</td></tr>
<tr><td rowspan="4">Solution path
Reproduce a definition of evaporation
or
Use the example provided to infer that water (liquid) has changed into invisible water vapour (gas)</td><td colspan="3">Demand</td></tr>
<tr><td>Reproduce
an answer</td><td>Apply
a known process to get an answer</td><td>Invent
a strategy to get an answer</td></tr>
<tr><td colspan="3">Learning required</td></tr>
<tr><td>Target concept only</td><td>Integrate near concepts
Target concept + other concepts from same learning area</td><td>Integrate far concepts
Target concepts + concepts from other learning areas</td></tr>
</table>

As measured by the task framework shown in

[8] A cloze exercise is an assessment item requiring students to supply a word or phrase to complete a sentence

Table 4-2, the challenge for this task is relatively low. The context contains minimal extra information about the disappearance of water from an open container at room temperature, and students could be expected to be familiar with this observation. Locating the concept of evaporation in the context removes the need for the student to use strategic knowledge. The prompt scaffolds the response by indicating that before and after terms are required, but no explanation is required.

Those students with a memorised definition of evaporation as a change from liquid to gas merely needed to reproduce this within the scaffold. This reproduction could even be done without reference to the context. For those without this cognitive resource, inferring the change from the context was more challenging as students needed to use the causal net associated with evaporation as a change of state between liquid and gas to complete the cloze exercise. They needed to read out disappearing water from the context and use the causal net to link evaporation as the cause of this. In neither case was any other learning needed. Some students may start with one strategy and use the other as a cross-check, but in either case, students will need either a readout strategy or a causal net for evaporation.

4.2.4.2 Question 21 evidence of transfer

The marking scheme accepted either the generic answer liquid to gas or the specific example liquid water to water vapour. Nationally 32% of Year 6 students were able to do this. Although it is not possible to find out exactly how the other 68% of students responded, the marking scheme lists liquid to air, water to cloud and water to steam as incorrect responses, suggesting that these were relatively common. All three indicate that the end product has gas-like properties but omit to name it as water vapour, showing a lack of precision in the language of their causal net. The air response could also indicate a larger misconception if it reflects thinking that water ceases to exist or changes into a new substance. In this question, a correct answer using the water context requires a degree of precision in language as it has to distinguish clearly between liquid water and water vapour. The responses involving air, cloud and steam are evidence of transfer of a general idea of water as a gas which requires refining to become a scientific explanation for evaporation. The framework for mapping grounded transfer is shown in Table 4-3.

Table 4-3 Grounded transfer of concepts in Question 21 &22.

Assessment of grounded transfer				
Code	Evidence of thinking	Response	Question 21	Question 22
NO	None	No new thinking – no response or reproduces given information		
NN	Relevant but not targeting the conceptual thread	Invokes other learning related to the task but not the target conceptual thread		*Sugar dissolving when stirred in water*
GL	Limited general knowledge	Either names or describes or misconceptions about a related general knowledge idea		
GT	Sound general knowledge	General knowledge idea relevant to and consistent with the targeted science concept	*Water to cloud* *Water to steam*	
SL	Limited knowledge about the science concept	Either names or describes or misconceptions about a related general knowledge idea	*Liquid to air*	*Ice melting*
ST	Sound knowledge of the science concept	Knowledge of parts of the targeted science concept and/or the connections between them	*Liquid to gas* *Water to water vapour*	*Wet footprints on concrete disappearing* *Clothes drying in the sun*

4.2.4.3 Question 22 task and affordances

The task analysis of question 22 is shown in Table 4-4.

Table 4-4 Analysis of NAP-SL 2012 Question 21 using task framework

Task Analysis			
Task challenge	Increasing intellectual demand→		
Context	Complexity		
Image removed – see fig 4-1	**Simplified real world**	More detail → Less detail→	Real-world Abstract
	Familiarity		
Four descriptions (total 17 words) of everyday phenomena	Rehearsed They have done this before	**Familiar** They have experienced this context but not with this learning	Unfamiliar They have not experienced this context
Prompt	Support		
Image removed – see fig 4-1	Scaffolded	**Cued**	Learner selected
Instructions to identify examples of evaporation. Bolded hint that multiple answers might be needed	Accountability		
	None Solution only	Elaborate Explain this answer	Consider alternatives Compare, Justify, Evaluate
Solution path	Demand		
For each example: read out a liquid and a gas and apply the causal net that the liquid needs to change into a gas to be evaporation	Reproduce an answer	**Apply** a known process to get an answer	Invent a strategy to get an answer
repeat for the remaining 3 examples	Learning required		
	Target concept only	Integrate near concepts Target concept + other concepts from same learning area	Integrate far concepts Target concepts + concepts from other learning areas

In question 22, four simplified contexts, all relating to water, were provided, and students could be expected to be familiar with each of these. The prompt asks students to identify those which involve evaporation, and the bolded hint that there could be more than one adds extra complexity to the task. The prompt cued the concept of evaporation, and students were primed by the question before. No explanation was required.

A solution path is to read out a liquid or a gas from each and invoke the causal net to identify a change from liquid to gas. Students could also use analogical thinking and look for the same disappearing water identified as evaporation in the previous question. The inclusion of the dissolving example in combination with the multiple responses requirement means that students had to be familiar enough with dissolving to discount it as an example of evaporation. Including it would score the whole response as incorrect, even if the other two examples had been correctly identified.

4.2.4.4 Question 22 evidence of transfer

Nationally, students did marginally better in this question, with 38% successful. The four individual options offered are mapped in Table 4-3. It is possible that despite the bolded instructions to tick all possible answers, some students will have provided only one correct answer, the usual requirement of a multiple-choice response. From the published material, there is no way of knowing how the 62% of students who were unsuccessful responded.

It could be anticipated that some students' responses will reflect guessing rather than transfer, and students are sometimes encouraged if not coached to do this rather than leaving an answer blank. This guessing ranges from a random guess from all offered responses to an informed guess where some are eliminated, narrowing the odds of correctly guessing. The possibility of multiple responses puts the frequency of randomly guessing the correct combination at 1/15 of 6.6%. The informed guesses, such as eliminating the dissolving option and guessing from the other three, blur this frequency considerably, so that all that can be said is that up to 38% demonstrated transferred of the states of matter by identifying both examples.

Looking at the two questions together[9]

up to 19% of students could define evaporation and identify the two examples (causal net and readout – possible evidence of science understanding)

at least 15% of students could define evaporation but not identify two examples (causal net, no readout – possible evidence of science rote learning)

Up to 15% of students could not define evaporation but could identify two examples (no causal net, but readout – possible evidence of everyday reasoning)

At least 52% of students could do neither (no evidence of science or everyday thinking)

Thus it appears that in 2012, less than 1/5 of Year 6 students transferred concepts related to change of state between liquids and gases in a formal testing situation, with a reasonable degree of precision by using either readout strategies and a causal net or possibly analogical thinking. (Schwartz et al., 2005) would class this task as sequestered problem solving - looking for transfer where you are least likely to find it.

---

[9] Using data obtained from ACARA in 2015 and not available from public release materials

4.2.5 Transfer in TIMSS

Unlike NAP-SL, which involves Year 6 students, TIMSS involves Year 4 and Year 8 students. In line with the published knowledge framework, questions directly assessing knowledge and understanding of states of matter occur only in the Year 4 version of TIMSS 2011, and so the results reflect the performance of students two years younger than those completing the NAP-SL tasks above.

4.2.5.1 Task analysis

Four items addressed states of matter, of which two involved changes of state and two about the properties of different states. These are analysed in Table 4-5.

Table 4-5 Task analysis and evidence of transfer in 4 TIMSS items

Task analysis												
	Identifies gas			Describes condensation			Temperature of ice, steam, water			Heat to change the state of water		
Context	Image removed due to copyright restrictions. See below table for link to image online. Description of a laboratory demonstration in third person with abstraction of objects, e.g. container X (49 words) and two labelled diagrams where containers represented by stylised cross-sections			none			Ice; water; steam			none		
Complexity	**Simplified**	Real-world **Abstract**		Simplified	Real-world **Abstract**		**Simplified**	Real-world Abstract		Simplified	Real-world **Abstract**	
Familiarity	Rehearsed	Familiar	**Unfamiliar**	Rehearsed	Familiar	Unfamiliar	Rehearsed	**Familiar**	Unfamiliar	Rehearsed	Familiar	Unfamiliar
Prompt	Image removed due to copyright restrictions. See below table for link to image online. Instruction to identify the diagram depicting the results of the change described in the context			Image removed due to copyright restrictions. See below table for link to image online. Instruction to identify before and after states in condensation			Image removed due to copyright restrictions. See below table for link to image online. Instruction to identify three states of water in order of increasing temperature			Image removed due to copyright restrictions. See below table for link to image online. Instruction to identify changes in state which require the addition of heat		
Support	Scaffolded	Cued	**Learner selected**	Scaffolded	**Cued**	Learner selected	Scaffolded	**Cued**	Learner selected	Scaffolded	**Cued**	Learner selected
Account-ability	None	**Elaborate**	Consider alternatives	**None**	Elaborate	Consider alternatives	**None**	Elaborate	Consider alternatives	**None**	Elaborate	Consider alternatives
Solution	Associate a gas with the property of filling its container and identify diagram			Identify condensation as a change from gas to liquid			Recognise ice as coldest, steam as hottest and water in between.			Associate boiling, melting and freezing with respective changes of state.		

Task analysis												
	Identifies gas			Describes condensation			Temperature of ice, steam, water			Heat to change the state of water		
path	3 as depicting this.									Associate that heat is needed with changes from solid to liquid to gas.		
Demand	Reproduce	**Apply**	Invent	**Reproduce**	Apply	Invent	**Reproduce**	Apply	Invent	**Reproduce**	Apply	Invent
Learning required	**Target only**	Near concepts	Far concepts	**Target only**	Near concepts	Far concepts	**Target only**	Near concepts	Far concepts	**Target only**	Near concepts	Far concepts
Assessment of grounded transfer												
Level of transfer												
NO												
NN	Because it looks like a gas											
GL	Gas just fills up											
GT	Gas would fill the space											
SL				Liquid changing to a solid Solid changing to a liquid Solid changing to a gas			Ice steam water Steam ice water Steam water ice			Only boiling requires heat Only melting requires heat Melting and freezing require heat		
ST	Gas does not have a definite shape or volume Gas takes any form in the container			Gas changing to a liquid			Ice water steam			Melting and boiling require heat		
ST Transfer	ST transfer **24%** (International average 16%-21%)			ST transfer **32%** (International average 28%)			ST transfer **83%** (International average 70% - 76%)			ST transfer **46%** (International average 43%-50%)		

Questions reproduced from (International Association for the Evaluation of Educational Achievement (IAC), 2013)

Origninal images available from https://nces.ed.gov/timss/pdf/TIMSS2011_G4_Science.pdf pages 65-66.

While the two NAP-SL questions focused on evaporation as a change from liquid to gas, the four TIMSS questions use a wider section of the causal net, including properties of gases, condensation as a change of state, relative temperatures of three states of water and the need for heat in changes of state.

Questions 2 and 4 are similar in the abstract context and differ from the NAP-SL evaporation question in that the solution path requires recognition rather than supplying the correct terms. Question 3 differs in providing a simplified context, with which students are likely to be very familiar, and it could be answered from everyday observations.

A different format was used for Question 1. There was a relatively extensive description of a task context with some abstraction, more closely resembling secondary science textbooks or exams, and thus likely to be unfamiliar to Year 4 students. The response also requires students to generate an explanation involving the behaviour of gases rather than simply recognise (or guess) a correct answer.

4.2.5.2 Evidence of transfer

Except for the question involving heat and change in the state of matter, Australian students did slightly better than the international average. In the familiar everyday context of the states of matter of water, 83% could identify the relative temperatures. This percentage halved when it came to the other multiple-choice questions requiring recognising the correct causal net for condensation as a change of state (32%) and heat input for change of state (46%). Because of the multiple-choice format, the only information about transfer other than that of the targeted concept lies in that anticipated by the distractors, which describe faulty causal nets.

Question 1 proved to be the most challenging for Year 4. Given that this concept is in the Year 5 curriculum and, with the possible exception of students in composite classes, had probably not yet been covered in school, it is not unsurprising that only 24 % of Australian students were successful in describing the property of a gas in filling its container. For the 76% who were unsuccessful, the marking scheme lists “because it looks like a gas” as a wrong answer, possibly because these students had only intuitive thinking about the situation.

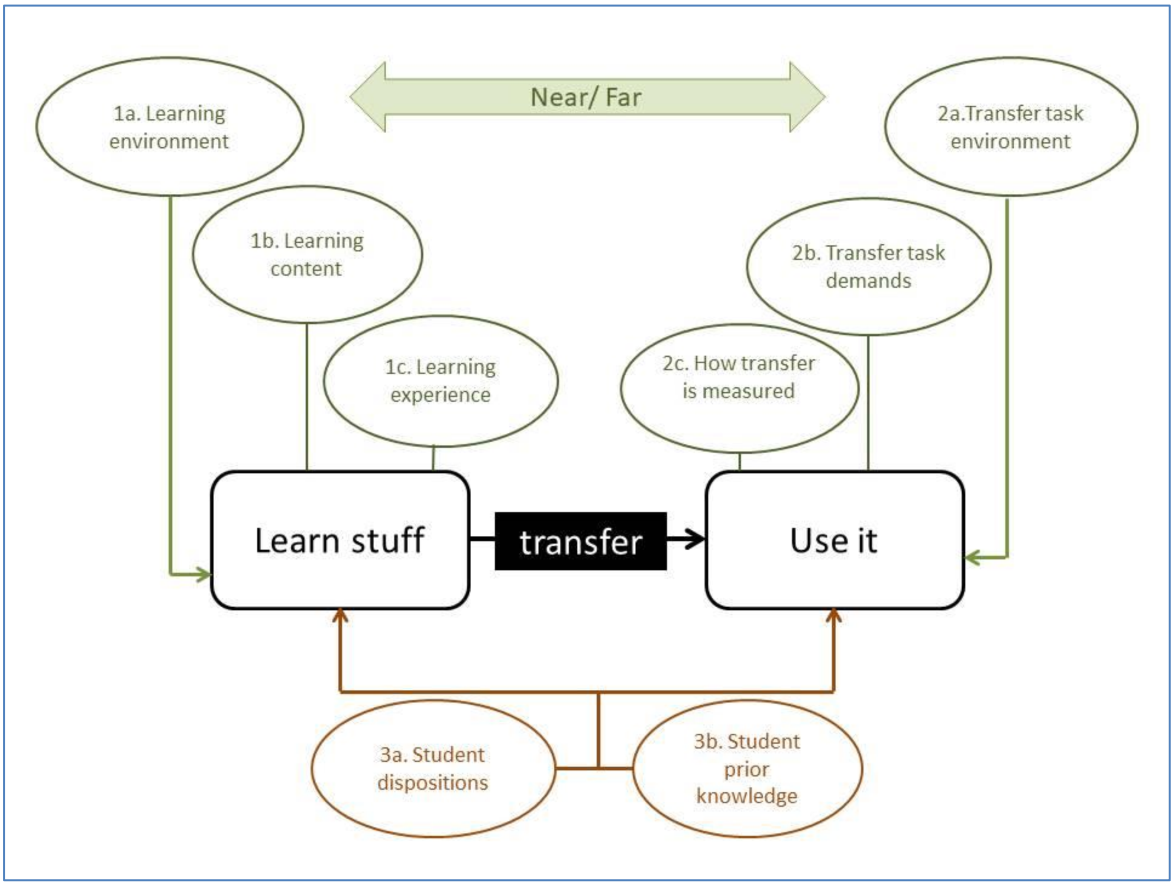
In questions 2, 3 and 4, multiple-choice with four options, the odds of guessing a correct response are 25%, which potentially reduces the rate of transfer from 32%, 83% and 46% to 7%, 59% and 21%. Without explanations of students’ thinking, there is no way of knowing how much guessing contributed to the apparent transfer of the targeted concepts in these questions. It is even difficult to compare between questions or cohorts of students since whether or not students elected to guess a response might vary with a range of factors such as whether they had been coached to game multiple-choice by informed guessing and whether the question was towards the end of the test and they were running out of time or concentration.

4.2.6 Factors affecting transfer

Standardised tests are used to measure transfer to compare groups of students. The frameworks have been used to describe the learning content and conditions of transfer in some test items. Here the factors that might have affected this transfer are considered. **Error! Reference source not found.** hows the three groups of these factors established in Chapter 3. Numbers have been added to indicate those associated with the learning (1a-1c), the transfer (2a-2c) and the learners (3a-3b).

Figure 4-2 Some factors affecting transfer of learning

(repeated from Figure 3 4 as an organiser for the following discussion of these factors)



4.2.6.1 Factors associated with the learning

4.2.6.1.1 Learning experience

These standardised tests were completed by a sample of students chosen to be representative of the larger cohort of Australian students at the respective year levels. The 2012 sample sizes were

NAP-SL 13,236 students and TIMSS 6,146. The sampling procedures were designed by the administering bodies to ensure representation of a number of groups including states and territories, suburban, regional and isolated students and Aboriginal and Torres Strait Islander backgrounds. Sampling procedures are covered in detail in the associated reports (Kesidou, 2012; Thompson, 2012). As such, it could be expected that they would have had a wide range of learning experiences associated with the science concepts targeted by the tests, and although some survey data was collected about this, little information is available about this that can be linked to their transfer in the test situation. The low performance of students in recognising or reproducing definitions could be because they had not been exposed to them, had not memorised them or had forgotten them.

4.2.6.1.2 Factors of the learning content

Until year 5, concepts in matter have largely involved physical properties and changes that are visible to students. Expanding the states of matter to include gases requires students to grapple with materials that are mostly invisible, and their existence and properties need to be inferred from other observations. The causal net also comes with a suite of terms such as condensation and evaporation to describe changes between the states, and both NAP-SL and two of the TIMSS tasks require students to associate these terms with the corresponding changes. The most transfer occurred in the temperature of states of matter task, which was free of change of state terminology, so possibly the relatively abstract nature of the concepts and the emphasis on terminology may have affected transfer.

4.2.6.1.3 Learning environment

As with learning experience, the sample could be expected to include students from a wide range of learning environments. No data was reported for this and so factors related to learning environment cannot be linked to the measured transfer.

4.2.6.2 Factors associated with the transfer

4.2.6.2.1 Factors of the transfer environment

Schools and teachers are aware that students will not receive individual reports on their performance in sample tests, and only minimal summary data is provided to the school. While some teachers may frame participation in the test to students as an opportunity to engage with something different or preparation for future tests in this format, others may see it as an unsolicited extra task, which is an extra imposition on an already crowded schedule. Student participation is likely to be influenced by their teacher’s framing. The similarity in format to the high stakes NAPLAN assessments may result in a carryover effect to the science tests, with students showing anywhere from high engagement to debilitating anxiety. One of the reasons given by the Australian Curriculum, Assessment and Reposting Authority (ACARA) for moving the tests online was to increase student engagement with contexts involving colour, simulations and interactivity, and it would be interesting to compare students' performance in both formats. However, the tests analysed here came from the monochromatic test booklet with handwritten answers model.

4.2.6.2.2 Factors of how transfer is measured

Tests were marked by panels of teachers and the published marking schemes for all questions measure targeted transfer of scientific concepts on a yes/no basis. Seldom (in fact, not at all in these examples) are there any options to record students' partial success with the concept, so the results are summative. Students either can or cannot successfully invoke and apply the concept. For teachers to investigate grounded transfer, they would need to take the questions back to their class and ask students to explain their thinking leading to their response. In the 2012 and previous versions of the test, one of the big positives for teachers was the bank of tasks that teachers could use to investigate grounded transfer by their students. These tasks are no longer made available with the move to online testing.

4.2.6.2.3 Factors of the transfer task

While the impact of many factors is speculative from the available data, standardised tests allow a closer examination of factors relating to the task. From the limited sample of items here, it is not possible to single out individual factors since differences between items involve combinations of factors. However, some factors which may have an impact are identified here.

Multiple-choice with a single response seems to measure transfer at a higher rate than those where more than one response is possible or where students must construct. Despite being two years younger and not having covered it in the curriculum, the proportion of students identifying the states of matter involved in condensation in the TIMSS item 1 was the same as the proportion of older students generating them for evaporation in the NAP-SL question 21. A solution path involving recognition (or elimination of wrong answers) seems easier than one where the terms have to be provided.

In TIMSS item 3, with its familiar everyday task context of ice, water, steam and their relative temperatures, combined with a multiple-choice response, transfer was high. However, transfer was harder to come by in TIMSS question 1, where the task context was complicated, abstracted, used unfamiliar representations and required a student-constructed explanation.

Accompanying the more complex task contexts are increasing literacy demands, which is an issue for especially students struggling with English as a second language. The two tasks with the highest word count had the lowest rate of transfer (NAP-SL q21 and TIMSS item 1). Images may have an ameliorating effect on this. An image of Luca's glass of water before and after might have helped some students make meaning from the 44 words of context. However, images also need to be accessible to students. The stylised diagrams used to convey the context in TIMSS item 1 may have been a challenge to students at Year 4 level, and the extra cognitive load required to interpret them may have interfered with their transfer of the targeted concept.

4.2.6.3 Factors relating to the students

Again the sample could be expected to include students with a range of prior knowledge and dispositions towards learning, but no data is available to link these to transfer.

4.2.7 Conclusion

These standardised test items measure targeted transfer, using a format outside the everyday classroom experience of most primary students. Successful transfer in these contexts is characterised by:

- expert-like use of terminology and perspective on the concept;
- a disposition to work individually rather than collaboratively and without access to other resources;
- engagement with problem contexts that may be presented in unfamiliar representation and disconnected from each other and other contexts students may be involved with;
- attention to discrimination of correct responses from others, some of which may appear reasonable to students for reasons other than those expected by the test writers; and
- management of various pressures related to the context, including time, anxiety about consequences of performance or disengagement with context;

Contexts like these are examples of sequestered problem solving (Bransford & Schwartz, 1999). They are useful for large scale data collection and comparison of groups of students but difficult to interrogate for reasons behind transfer, especially failure to transfer. In the next section, transfer is investigated in classroom tasks which offer the potential for a finer-grained analysis of what was and was not transferred.

4.3 Transfer in classroom tasks

4.3.1 Introduction

The items from large scale standardised testing examined in Section 1 offered affordances for students to transfer an expert's perspective on concepts, and many students failed to demonstrate this, with about 80% of the 2011 Year 6 students not completing a cloze exercise defining evaporation and identifying examples of evaporation in everyday scenarios. While the tests show students' failure to demonstrate targeted transfer, they say little about their grounded transfer or what they did transfer. This information is vital for teachers in identifying how to address the failure of targeted transfer.

An extended response task offers more affordances to investigate grounded transfer since student responses are not limited to single words or choosing between given options (Pegg & Tall, 2005). This section used work samples from an extended response task to investigate grounded transfer of the states of matter concept by Years 5 and 6 students.

4.3.2 Method

The work samples for this study were collected and used primarily for the in-school professional development of teachers. Students completed a task involving the Australian Curriculum Science Chemical Sciences Year 5 content of the properties of solids, liquids and, in particular, gases in the context of a burning candle. The professional development involved tracing the development of concepts in chemical sciences. Some time after the professional development was completed, ethics permission was sought and received from the relevant ethics committees to use the work samples in this study (see Appendix H).

4.3.2.1 Participants

Participants were 50 students in a large metropolitan Adelaide primary school, representing about one third of the school's enrolment at the year levels involved. The school ranks higher than the Australian average in the Index of Cultural, Social and Educational Advantage (ICSEA) published on the *My School* website[10]. The students were selected because their teachers had volunteered to collect work samples for professional development. This section uses work samples from the students in Year 5 (n=25) and Year 6 (n=25).

[10] https://www.myschool.edu.au/

4.3.2.2 Task

The task was developed to assess students' understanding of the chemical sciences concepts in the Year 5 Australian Curriculum: Science (ACARA, 2021a). In this curriculum, the chemical sciences are organised into two parallel concept threads: properties of materials and changes to materials, and although both threads are involved in the states of matter concept, the emphasis is on properties of the different states. The relevant parts of the curriculum at each year level are shown in Appendix I.

The task consisted of three parts:

- annotate a diagram of the unlit candle, focusing on properties of materials thread;
- draw and annotate a diagram showing how the candle changed as it burnt, focusing on the solids, liquids and gases; and
- choose a statement from the four provided and use an example to explain it (Explain with example task).

In combination, the first two parts addressed the curriculum concept for the current year level in the context of the candle. The third part offered students the opportunity to explain a generalised statement within their own choice of context. The task record sheets and the four statements for the third part (*Explain with example*) of the task are shown in Appendix J.

4.3.2.3 Procedure

The task was administered in students' regular classrooms by the classroom teacher and the researcher as partnership learning improvement leader. It was framed in terms of teachers being interested in students' thinking in science to improve teaching and learning. In response to a question about whether it would affect their grades, students were told to see it as an opportunity to demonstrate learning they might not yet have had already done. The introduction to the task included an example of an annotated diagram of a pencil and an explanation of behaviour expectations for safety with lighted candles. The introduction and candle task took about 40 minutes. Student engagement was observed to be high, and compliance with the safety rules was universal.

The lesson procedure was:

- Students were provided with a birthday candle, an aluminium dish and a piece of plasticine and asked to describe the properties of the materials and how they related to their uses by annotating a diagram.
- The candle was then lit, and they were asked to describe the changes to the materials, particularly those involving solids, liquids and gases.

- After this was completed, they were given four statements about gases and asked to choose one that they could explain using an example:
    - Gases are invisible;
    - Gases spread through the air;
    - Gases have no shape or size; or
    - In gases, the particles are fast-moving and far apart from each other.
    - After 30 to 40 minutes, work samples were collected, and students were thanked for their participation.

The first part of the task, where students annotated a diagram of the unlit candle, provided an opportunity to demonstrate transfer of the concept of properties of materials affecting their uses from the Year 4 science curriculum and is not directly relevant to states of matter.

4.3.3 Results

4.3.3.1 Candle changes task

4.3.3.1.1 Learning content

The learning content involving states of matter was the same as in the previous section, as mapped out in Table 4-1.

4.3.3.1.2 Task and affordances

This task, where students constructed and annotated a diagram to show changes as the candle burnt, provided an opportunity to demonstrate transfer of the concepts associated with gases from the Year 5 curriculum. This task is analysed in Table 4-6.

Table 4-6 Analysis of the Changes to a candle task using the task analysis framework

<table>
<tr><th colspan="4">Task Analysis</th></tr>
<tr><td>Task challenge</td><td colspan="3">Increasing intellectual demand→</td></tr>
<tr><td rowspan="4">Context

Birthday candle supported by plasticine in an aluminium dish
Outline diagram of the candle</td><td colspan="3">Complexity</td></tr>
<tr><td>Simplified real world</td><td>More detail →
Less detail→</td><td>Real-world
Abstract</td></tr>
<tr><td colspan="3">Familiarity</td></tr>
<tr><td>Rehearsed
They have done this before</td><td>Familiar
They have experienced this context but not with this learning</td><td>Unfamiliar
They have not experienced this context</td></tr>
<tr><td rowspan="4">Prompt

Draw a second outline diagram of the candle showing how it changes when it has been burning for a while. How are solids, liquids and gases involved?</td><td colspan="3">Support</td></tr>
<tr><td>Scaffolded</td><td>Cued</td><td>Learner selected</td></tr>
<tr><td colspan="3">Accountability</td></tr>
<tr><td>None
Solution only</td><td>Elaborate
Explain this answer</td><td>Consider alternatives
Compare, Justify, Evaluate</td></tr>
<tr><td rowspan="4">Solution path

Identify the dripping wax as liquid because of its loss of fixed shape. Infer that the burning flame is producing invisible gases or read out the observed behaviour of the smoke produced when the candle is blown out as a gas</td><td colspan="3">Demand</td></tr>
<tr><td>Reproduce
an answer</td><td>Apply
a known process to get an answer</td><td>Invent
a strategy to get an answer</td></tr>
<tr><td colspan="3">Learning required</td></tr>
<tr><td>Target concept only</td><td>Integrate near concepts
Target concept + other concepts from same learning area</td><td>Integrate far concepts
Target concepts + concepts from other learning areas</td></tr>
</table>

This task has some challenging features. The real-world context was highly engaging but potentially distracting. Although the states of matter concept was cued (and students' attention was drawn to this by being directed to underline these three words in the prompt and double underline the word *gases*), the prompt required explanation rather than just identification of solids, liquids and gases. Affordances were there for students to read out examples of liquids (molten wax) and gases (smoke, products of the flame) and properties of shape, size, flow, and use the causal net, explaining how these properties classify materials into states of matter. This thinking is aligned with the Year 5 curriculum.

The task differs from those in the standardised testing described above in that:

- the context was presented through firsthand experience of physical materials rather than a text description;
- although students were required to produce individual responses, they could discuss ideas. Many students took up this opportunity;
- the task required an extended response, and several different responses could be provided, eliminating the need to select a single best answer; and
- although the concept of states of matter was cued, students had to use readout and their causal net to invoke the key properties distinguishing gases from liquids.

4.3.3.1.3 Evidence of transfer of science ideas related to gases.

Student responses are summarised in Appendix G. Of the 25 students, 19 (76%) transferred some aspect of gases in their response. In 11 of these, the response was limited to a readout of gases, usually smoke but occasionally nonspecific gases located adjacent to the flame. Two students linked these to a causal net, one describing gases as produced by evaporation and the other reasoning that the smell of smoke throughout the room indicated that gases were present. The seven students with limited responses either identified fire or the flame as a gas or observed a gas like property of smoke without actually naming it as a gas.

The remaining students who did not invoke anything relevant to gases limited their responses to visible changes – 4 to changes signifying formation of liquid wax and 3 to observations of the burning candle, e.g. the wax gets shorter; the wick goes black.

Thus, while about three-quarters of students demonstrated a readout of gases, none invoked a causal net involving changes in key distinguishing properties of gases. The *Explain with example* task provided opportunities to do this without the distractions of the real-world context.

4.3.3.2 Explain with example task

4.3.3.2.1 Learning content

Again the learning content about states of matter is mapped out in Table 4-1.

4.3.3.2.2 Task and affordances

In this task, students were given the following four statements about gases and asked to choose one that they could explain using an example:

- Gases are invisible;
- Gases spread through the air;
- Gases have no shape or size; or

- In gases, the particles are fast-moving and far apart from each other.

This task removed the need for strategic thinking and readout and directly cued the causal net. The analysis is shown in Table 4-7.

.

Table 4-7 Analysis of the statement explanation task using the task analysis framework

Task analysis			
Task challenge	Increasing intellectual demand→		
Context	Complexity		
None given; students invited to generate their own example	Simplified real world	More detail → Less detail→	**Real-world** **Abstract**
	Familiarity		
	Rehearsed They have done this before	**Familiar** They have experienced this context but not with this learning	**Unfamiliar** They have not experienced this context
Prompt	Support		
Use an example to explain one of these statements	Scaffolded	**Cued**	Learner selected
	Accountability		
	None Solution only	**Elaborate** Explain this answer	Consider alternatives Compare, Justify, Evaluate
Solution path	Demand		
Choose 1 statement that you can elaborate on. Identify an example and describe the idea from the statement in the context of the example.	Reproduce an answer	**Apply** a known process to get an answer	Invent a strategy to get an answer
	Learning required		
	Target concept only	Integrate near concepts Target concept + other concepts from same learning area	Integrate far concepts Target concepts + concepts from other learning areas

The prompt to use an example allowed students to demonstrate that they could find an appropriate context and read out the relevant aspects. The generic statements about gases provided affordances for students to describe causal nets at varying degrees of sophistication from an everyday observation to the defining behaviour and properties of gases and, finally, the use of particle theory to explain these. Although the four statements were presented in order of their degree of sophistication, this order does not necessarily apply to the response. For instance, students could (and did) use particle theory to explain why gases were invisible.

The key differences from the candle changes task are the student choice of statements and the abstract context of all four statements with the requirement to generate their own real-world context as an example.

4.3.3.2.3 Evidence of transfer

Student responses are summarised in Appendix H. The challenge in assessing transfer in this task is to discount responses where they had added no new ideas to those presented in the prompts as between the four prompts, it was possible to string together a quite convincing explanation, e.g. *gases spread really fast through the air*; *gas particles are spread apart*. Even those students who did add new ideas or connections often included some rearranged ideas as well.

Of the 25 students, 23 (92%) transferred something about gases. Three (12%) used the idea of shape to describe a property; ten (40%) had a more idiosyncratically worded explanation using terms like *float, always moves around*, *moves as much as it wants,* and four (16%) were limited to providing examples of gases, smoke, air and oxygen, with no causal net. Another five showed a misconception or limited idea about gases, e.g. *fire and water vapour aren't invisible*; *gases aren't trapped inside something like solids.* One student produced a generic *air is everywhere,* which did not offer enough to be a convincing description of diffusion. The remaining three (12%) offered no new information.

Given that the causal net was cued in the prompt, it is unsurprising that this question delivered a higher rate of transfer (92% compared with 76%), with over half (52%) transferring some part of the causal net.

The quasi multiple-choice in the *Explain with example* task was intended to support grounded transfer by providing options at a range of levels, increasing the number of students who could access the task. While compared to all the other options, twice as many students chose the *gases have no shape or size* option. Interestingly, there was no direct correlation between the level of the option students chose to explain and the level of the explanation. All five students who chose to explain option B transferred at ST1 or above, while three of the 11 students who chose option C transferred below ST1 level.

4.3.3.3 Collective and individual transfer

As a class, the group demonstrated transfer of:

- the properties and behaviour of gases – shape, size and the tendency to disperse through a container or the atmosphere, illustrated with examples like smoke and air;
- smoke and air as examples of gases;
- wax as a liquid and the role of heat in the change from one state to another;
- some appropriate use of terminology (gas, liquid, melt) and a wide range of imprecise and idiosyncratic use of language such as gases *floating* or *going anywhere it wants;*
- some misconceptions involving fire or flame as a gas;

- some over generalisations (*e.g. all gases are invisible*); and
- some irrelevant detail (e.g. only animals can breathe underwater).

Many individual responses appeared to be jointly constructed (usually between two students), which was not prohibited in this activity. This joint construction could range from verbatim copying others' work to jointly constructed and individually verified thinking, although distinguishing where a particular response lies on this continuum is difficult in this context. Students can engage with joint construction of responses with different goals. Seeking to validate their own thinking or learn from others' thinking would be characteristic of mastery goals or if paired with a capable partner, performance-approach goals. Complaining about being copied might also reflect performance-approach goals, especially if paired with a less capable partner, where the student is focused on a response better than others. It likely reflects a performance-avoidance goal for the copier, i.e. avoiding being seen to do badly. All three of these scenarios may have occurred during this task.

Of the 25 responses, two sets each of two responses were identical in wording, layout and diagram conventions for both tasks. In one of each pair, there was evidence of erasing previous records, suggesting that the student had abandoned their previous attempt in favour of that recorded by the other student. Especially in the third part, the changed records fall short of the detail provided by the other student, possibly because the copier ran out of time.

Because teachers and researchers do not know whose thinking is recorded, joint construction is an annoyance when the purpose of the activity is to assess individual learning. However, it could be a powerful tool for promoting learning if students engage with it with mastery goals and could be leveraged to improve individual capacity.

4.3.3.4 Factors affecting transfer

Table 4-8 compares the number of students transferring at each level in the two tasks.

Table 4-8 Comparison of transfer in two classroom tasks (n=25).

Shaded cells show transfer at the same level in both tasks.

		Candle changes task								*Explain with example* task totals
		NO	NR	GL	GT	SL	ST1	ST2	ST3	
Explain with example task	NO	0	0	1	0	0	0	0	0	1
	NR	1	0	0	0	1	1	0	0	3
	GL	0	0	0	0	0	1	0	0	1
	GT	0	0	0	0	0	0	0	0	0
	SL	0	0	0	0	1	1	1	0	3
	ST1	0	1	0	0	1	2	0	0	5
	ST2	0	1	1	1	1	5	1	0	10
	ST3	0	0	0	0	2	1	0	0	3
Candle task totals		1	2	2	1	6	11	2	0	

Overall there was more targeted transfer for the abstract *Explain with example* task (18 - 72%) than the real world candle changes task (13 - 52%), which could be attributed to either the distracting real-world context inhibiting transfer or the *Explain with example* task cuing the causal net supporting transfer. Only one student (4%) transferred a causal net in both tasks. Twelve students (48%) who did not describe a causal net about gases in the candle task did so in response to the abstract prompt. Conversely, four (16%) students did not supply either a causal net or an example of a gas in the abstract *Explain with example* task but had done so in the candle changes task.

Thus students' causal nets about the defining properties and behaviour of gases seem largely independent of their observations and thinking about the candle. Although most were able to read out a gas from the burning candle context, there is almost no evidence of this being linked to the causal net. In those causal nets in the abstract, *Explain with example* task that did involve an example, it was most commonly air rather than any gases related to the previous task. In terms of the SOLO framework of Biggs and Collis (1982), the students completing this task are multi-structural in their thinking about gases; they can readout gases from a context and describe the causal net around the key properties, but while a few are exploring the links, many have yet to see connections. In the view of Perkins and Salomon (2012), applying the causal net to the candle context was a bridge too far.

4.3.3.5 What constitutes evidence of satisfactory achievement?

Up to here, the mapping of transfer has described what learners did and did not transfer, both in terms of the targeted concept and other ideas. This addresses the needs of researchers looking at factors affecting transfer and educators seeking the prior knowledge that students bring. However, educators also have to make judgements about transfer to report to parents and the system on how well students have met the curriculum standards.

4.3.3.5.1 Evidence of transfer as described by the Australian Curriculum achievement standard

The relevant Australian Curriculum: Science (ACARA, 2021a) for the year 5 students in this study has been described in Table 4-1.

The year level description indicates that this learning extends Year 3 learning by adding gases to the solids and liquids classification they acquired in Year 3. It primarily focuses on properties of materials rather than change of state. The content description makes it clear that the classification criteria are the properties and behaviour that distinguish the three states of matter, and the achievement standard specifies that students can use these properties to classify. In the candle task context, this would look like students identifying smoke or other gases associated with the burning candle as gases because they have no fixed shape or size and disperse through the air. This learning was described in the concept outline of the table in Table 4-1.

Across individual responses to both questions, the following were seen:

- identifies smoke, air or flame as a gas with no reasoning;
- describes one or more of the criteria of no fixed shape and size and a tendency to disperse as key to distinguishing gases. They may have used the science terminology as given here or involved a range of other idiosyncratic uses of language; and
- describes one or more criteria as in b), linking them to an example, either recalled or from the candle context.

The issue for teachers is which of these demonstrate satisfactory achievement of the standard.

4.3.3.5.2 ACARA work samples

To assist with this, ACARA has published work samples, one for each level of achievement – below standard, at standard and above standard. The task relevant to solids, liquids and gases was a worksheet with four questions, shown in Figure 4-3**Error! Reference source not found.**.

Figure 4-3 Work sample from ACARA Australian Curriculum satisfactory portfolio

Image removed for copyright reasons. Original can be viewed online at

https://docs.acara.edu.au/curriculum/worksamples/Year_5_Science_Portfolio_Satisfactory.pdf

(pages 4&5)

Image removed for copyright reasons. Original can be viewed online at

https://docs.acara.edu.au/curriculum/worksamples/Year_5_Science_Portfolio_Satisfactory.pdf

(pages 4&5)

Of the four questions, a minority relate to gases, and the affordances of these are described below. In addition, the ACARA website annotates the work samples to describe the key features distinguishing satisfactory from below satisfactory and above satisfactory achievement. Table 4-9 summarises these differences.

Table 4-9 Distinguishing features of achievement levels in ACARA work samples

(student responses shown in italics.)

Question	Affordance	Below satisfactory	Satisfactory	Above satisfactory
2a	recognise that gases "fill the shape of the container"	no	no	yes
2c	recognise air as an example of a gas	yes	yes	yes
2e	identify a gas as the product of boiling water	no	yes	yes
2f	identify that gases (along with the other states) have mass	no	no	Yes
4	classify common features of solids liquids and gasses	*Gases stink*	*Misty* *Liquid can change into a gas*	*flows, fills container, mass, take up space, begins to use particle model*

Question 2 required students to match six statements to the appropriate state of matter. Two involved using the shape causal net, although "It fills the shape of the container" is slightly ambiguous. Does 500ml of water in a litre container fill the "shape", even if it does not fill the entire container? Only the above satisfactory student included the gas in this. Question 2c required students to read out air as a gas, which everybody did. Question 2e involved the change of state from liquid to gas which both the satisfactory and above satisfactory students did successfully. The final statement was about weight, which only the above satisfactory student could do. That gases have weight addresses an important misconception but does not distinguish them from other states of matter.

Question 4 invited students to use a Venn diagram to show what they knew about solids and liquids with a prompt to use the overlapping parts to show common features. The satisfactory student identified that gases were misty or vaporised liquid. The above satisfactory student referred to particle theory and key properties of shape and flow. The below satisfactory student recorded that solids were hard and still and liquids runny. Students seemed challenged by the representation required, with only the above satisfactory sample showing appropriate use of the overlapping areas.

Regarding what counts as satisfactory achievement of the standard, the work samples seem to be at odds with the curriculum year level description. If the addition of gases to the classification schema is the significant new learning at Year 5, then it is curious that most of the task assessed change of state from solid to liquid, which is Year 3 level. The knowledge of gases demonstrated by the satisfactory achievement sample is limited to:

- Air is a gas;
- If you boil water it will makes a gas;
- Gases are misty; a thin layer of vaporised liquid;

and includes misconceptions or missed opportunities:

- Gas doesn't fill the shape of its container;
- Gas doesn't have weight;
- No common features with liquids or solids;
- No defining features that distinguish gases from the other states.

These responses seem far from the "classify substances according to their observable properties and behaviours" specified in the achievement standard and at odds with the degree of precision of language required in the NAP-SL question.

The above standard student also recognised from a list of properties that:

- Gases fill the shape of their container;

and volunteered that:

- They flow;
- The particles are far apart;
- Fill the container.

This response would seem to align with satisfactory achievement of the standard.

In defence of ACARA, it should be noted that evidence of satisfactory achievement is considered as an on-balance judgement of the entire portfolio of six tasks and may not apply to every task.

Evidence of transfer of other year level science learning

The transfer of learning outcomes from other years could be evidence of transfer as preparation for future learning (Bransford & Schwartz, 1999). As a class group, there was evidence that students could:

- describe properties of the materials (F;)
- describe changes to the materials as the candle burns (Year 1);
- describe uses of the materials in this context (Year 2);
- identify in the melting wax a change of state from solid to liquid and back again; and

- link the properties of materials to their uses, especially in the plasticine and aluminium foil dish (Year 4) although there was less agreement over the role of the wick and the wax in the candle.

Although there was variation in what individual students provided evidence of, there is evidence that the group has brought learning from previous years to a science task at their current year level.

4.3.4 Discussion - Factors affecting transfer

Classroom tasks offer an opportunity to consider factors affecting transfer of learning in a different environment to that of standardised testing. While some factors are the same for both situations, several differences are expanded on below.

4.3.4.1 Factors associated with the learning

4.3.4.1.1 Learning experience

This task was completed by a single class of Year 5 students, so presumably, the learning experiences were similar for each student. Little is known about how the topic was taught except for the mention of a video on particle theory and states of matter by one student. There was little evidence for transfer of any part of the causal net involving the connection between particle theory and gas behaviour, since all four students who mentioned particles in their response added no extra information to that given in the fourth statement of the prompt.

4.3.4.1.2 Factors of the learning content

Transfer in the classroom tasks supports the suggestion from Chapter 4.2 that less concrete content is harder to transfer since transfer of the causal net related to the gas part of the causal net was less frequent and at a lower level than that of the observable changes to liquids or solids.

4.3.4.1.3 Learning environment

As the students all came from one class, relatively similar physical learning environments could be expected, but their affordances for action in this environment may have differed. Almost certainly, their experiences of the social environment will have differed depending on with whom they interacted. As no data was collected on students' experience of the physical and social environment, it is not possible to compare factors relating to these.

4.3.4.2 Factors associated with the transfer

4.3.4.2.1 Factors of the transfer environment

The task was carried out in the students' regular classroom - the same environment where students would have learnt the ideas. The differences for this task were the presence of the school learning improvement leader and the knowledge that as well as their class teacher, other teachers would be looking closely at their responses. In addition, there was no input about learning content from the supervising teachers. Observation of student engagement by the teacher and learning leader at the time of the task and the detail of their responses suggested that the vast majority of students took the tasks seriously.

4.3.4.2.2 Factors of how transfer is measured

Student responses were examined for grounded transfer as parts of the causal net related to liquids, and misconceptions about gases were noted as well as sound ideas about gases. Including the misconceptions and limited conceptions provides evidence of those students who can read out a gas but not invoke a causal net related to distinguishing properties. From the teacher's perspective, it becomes clear that the distinguishing properties of gases need to be targeted.

As for targeted transfer, there is also evidence that at least some students can reproduce a causal net for some properties of gases. On the basis of the ACARA work samples, 'the bar' for satisfactory achievement is not very high.

4.3.4.2.3 Factors of the transfer task

The tasks involved some potentially unfamiliar features. The candle changes task was based on physical materials (including the usually forbidden fire), and it required the construction of an annotated rather than labelled diagram. The Explain with example task offered a choice of ideas to explain, and using an example to support the explanation was not done well. If used at all, examples were simply named rather than providing a context for the explanation. It could be expected that the ideas in the four prompts would cue transfer in the Explain with example task, so transfer shown in this task is effectively functional - the reproduction of a causal net.

Again it is not possible to single out the effect of individual factors, although it seems that more students transfer in tasks requiring the reproduction of an abstract causal net rather than those requiring interpretation of this causal net in a context.

4.3.4.3 Factors relating to the students

Compared to the tens of thousands of students involved in standardised tests each year, the 25 in this class could be expected to include a somewhat narrower range of prior knowledge and dispositions towards learning. However, there is no data describing this range to link these to transfer.

4.3.5 Conclusion

This study supports the suggestion from Chapter 4.2 that factors relating to the learning content and the transfer task affect the transfer demonstrated. In addition, it indicates that how transfer is measured is another factor affecting transfer. Finally, the absence of data on factors of the learning experience and factors relating to students themselves, e.g. prior knowledge and learning dispositions, points to the need for data on these to better understand the range of factors affecting transfer. Classroom experiments on transfer of learning need to include data collection on students' dispositions, perceptions and experiences of the learning and transfer.

Some of the factors affecting transfer relate to the students themselves, such as their age and associated developmental stage. While this study has targeted upper primary students (Years 5 and 6; 10-12 years of age), the following section looks at transfer of science concepts by students in the years before this.

4.4 Transfer in classroom tasks R-7

4.4.1 Introduction

The studies discussed in Sections 1 and 2 indicated that many students in Years 4-6 of primary school did not transfer targeted curriculum concepts in classroom and standardised test tasks and that factors related to the learning content, the transfer task and how transfer is measured may affect this. In this section, the focus changes to how this situation developed. In South Australia, most students in government schools begin school at the end of January between the ages of four years and nine months and five years and nine months. This school year is named Reception and the following year is Year 1. When this study was carried out, the last year of primary school for most government schools was Year 7, although this is due to change in the 2022 school year. The study in this section investigates transfer of the curriculum science concepts for students in the years from Reception to Year 7.

Data analysis for this section was carried out before the frameworks described in Chapter 3 were finalised; in fact, the process of interpreting the data from this set of work samples informed the development of the frameworks rather than the other way around. Despite this difference in the way transfer was assessed, the findings contributed to the research question of which factors affect transfer by providing further evidence of factors related to the concepts to be transferred and to the transfer task and by pointing to a need to investigate factors related to the learning experience and the students themselves. Finally, the study provides evidence of several classroom phenomena that teachers regularly encounter in their work, but research often overlooks.

4.4.2 Method

The work samples for this study were collected and used primarily for the in-school professional development of the teachers of these classes. Students from Reception to Year 7 completed a task with the same context, a burning candle, but with a prompt addressing the chemical sciences understanding for their particular year level. The professional development involved tracing the development of concepts in chemical sciences from Reception to Year 7 level. Some time after this was completed, ethics permission was sought and received from the relevant ethics committees to use the work samples in this study (see Appendix H).

4.4.2.1 Participants

Participants were 203 students in a large metropolitan primary school. The school ranks higher than the Australian average in the Index of Cultural, Social and Educational Advantage (ICSEA) published on the *My School* website[11]. The students ranged from 5 to 13 years of age and from their first to their eighth year of schooling. Included in the study were participants at every year level. Participants represented about half of the school enrolment and were selected because their teachers volunteered. Students in classes with two year levels participated at their level of enrolment.

The demographic details for the 203 participating students have been described in section 4.2.2.1. The distribution of students across the seven classes involved is shown in Table 4-10.

Table 4-10 Distribution of participants in classes

	Year								
Class	F	1	2	3	4	5	6	7	**total**
A	24								24
B		11	11						22
C			13	12					25
D					28				28
E						25			25
F							25		25
G							11	41	52
total	24	11	24	12	28	25	36	41	

4.4.2.2 Task

The task was developed to assess students' understanding of the chemical sciences concepts from the relevant year level of the mandated Australian Curriculum: Science (ACARA, 2021a). In this curriculum, the chemical sciences are organised into two parallel concept threads: properties of materials and changes to materials, and usually, any particular year level focuses on one of these. In Year 3, for example, students look at changes in state between solid and liquid, while in Year 4, the concept is around how the properties of materials affect their uses. Although both conceptual

[11] https://www.myschool.edu.au/

threads are involved in each year level, the emphasis at any one particular year level tends to lie more with one than the other. The relevant parts of the curriculum at each year level are shown in Appendix I.

The task consisted of three parts:

- annotate a diagram of the unlit candle, focusing on properties of materials thread
- draw and annotate a diagram showing how the candle changed as it burnt, focusing on the changes to materials thread
- choose a statement from the four provided and use an example to explain it.

In combination, the first two parts addressed the curriculum concept for the current and previous year levels in the context of the candle. The third part offered students the opportunity to explain a generalised statement within their own choice of context. The task record sheets and the four statements for the third part of the task are shown in Appendix J.

4.4.2.3 Procedure

The procedure was described in 4.3.2.3. The tasks were conducted by the researcher in students' regular classrooms. The only modification for younger students was made for Reception students, whom the classroom teacher coached in constructing diagrams after their first attempt. As part of the original professional development activity, some teachers followed up the initial responses with feedback targeting the level of understanding of individual students. The additional student responses from these have been included where stated. These were run by the teachers, not the researcher.

4.4.3 Results

4.4.3.1 Transfer of the intended learning

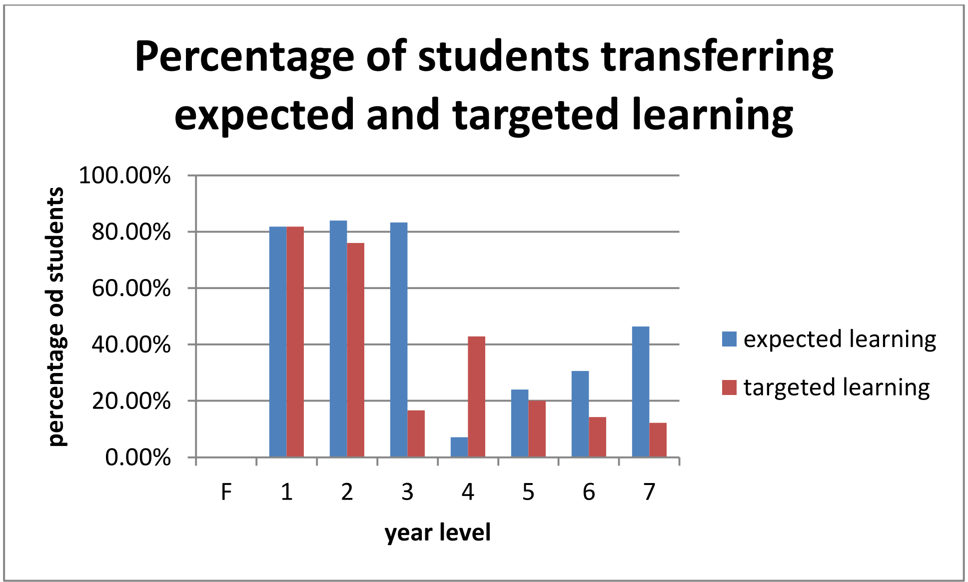
Student work samples were analysed for transfer of the intended learning using the conceptual understanding strand (Strand C) of the National Science literacy progress map (Connolly, 2017 p 185). The interpretation of this map in the candle task is shown in the last column of Appendix I. Responses were scored as 0 to 4 according to the four levels described.

The actual level of learning expected of these students is not clear. This task was run in mid-September, at the end of the third term of school for that academic year. The Australian Curriculum Science Achievement Standard reads "By the end of Year…, students …" so that it could be argued that students had another three months to acquire this learning. For this reason, two levels have been identified in the data below: that *targeted* by the curriculum for the particular year level (highlighted in red in Table 4-11) and that which could be *expected* from the year level below (highlighted in blue in Table 4-11). There are different issues associated with each of these. The students may not yet have been exposed to targeted learning, and consequently, the frequency of transfer would be low. If the targeted learning had been taught in class this year, it would be more recent, or nearer transfer according to (Barnett & Ceci, 2002), than the expected learning from last year and consequently more likely to be transferred. Transfer of targeted and expected learning is shown in Table 4-11 and **Error! Reference source not found.**.

Table 4-11 Percentage of students transferring expected (blue) and targeted (red) learning.

Year	n	Properties thread	level	%	Changes thread	level	%
F	24	Describes a property	1	0	Describes a change	1	17
1	11	Describes a property	1	82	Describes a change	1	82
2	25	Describes a use or purpose	1	76	Describes a change	1	84
3	12	Describes a use or purpose	1	100	Links cause and effect in a change	2	17
4	28	Links a property to use	2	43	Links cause and effect in a change	2	7
5	26	Links a property or behaviour to use or classification (gas)	3	28	Links cause and effect in a change	2	24
6	36	Links a property or behaviour to use or classification (gas)	2	31	Identifies reversible and irreversible changes	3	14
7	41	Links properties to separation technique	3	15	Identifies reversible and irreversible changes	3	46

Figure 4-4 Percentage of students transferring expected and targeted learning



Targeted transfer was high in Years 1 and 2 and then declined, coinciding with the requirement for an explanation rather than a description (Years 3 and 4). This trend continued when a generalisation was called for (Years 5 and 6). Likewise, transfer of the expected learning also declined once past the description stage, although except for Years 4 and 5 transfer was better the following year when it became expected learning. The improvement in transfer of the learning in the year after it was targeted may indicate that the learning was taught in the fourth term of the previous year or that the concepts continued to develop with other science and world experiences for some students. This improvement was not seen in Years 3 and 4, which were lower in the following year. Again these level 2 outcomes are the first two requirements for connections rather than descriptions. These connections between ideas seem easier to transfer when they are a link between properties and uses rather than a cause and effect between heat and a change of state.

Table 4-12 shows the level of transfer of all students, including those not transferring at the expected or targeted levels (shaded in green).

Table 4-12 Level of transfer of science concepts in candle task.

Targeted (red); expected (blue); residual (green)

Year	n	Properties thread level					Change thread level				
		0	1	2	3	4	0	1	2	3	4
F	24	100 %	0%	0%	0%	0%	83%	17%	0%	0%	0%
1	11	18%	82%	0%	0%	0%	18%	82%	0%	0%	0%
2	25	24%	76%	0%	0%	0%	16%	84%	0%	0%	0%
3	12	0%	83%	17%	0%	0%	17%	67%	17%	0%	0%
4	28	4%	54%	43%	0%	0%	7%	86%	7%	0%	0%
5	26	0%	12%	68%	28%	0%	4%	72%	24%	0%	0%
6	36	3%	64%	31%	0%	0%	0%	63%	20%	14%	0%
7	41	0%	56%	29%	15%	0%	0%	27%	27%	46%	0%

* The candle task prompts did not prompt students to show level 4 thinking (explaining separation of mixtures using particle theory).

Up to Year 3, relatively few students demonstrate no transfer of the ability to describe relevant aspects, and at least some of the failure to transfer could likely be attributed to literacy issues. However, after Year 3, when they should be working at level 1 (describing observations) and progressing to level 2 (describing change or difference), many students continued to demonstrate no higher transfer than level 1, still describing single aspects of the candle.

These are displayed by year levels in the following sequence of charts (**Error! Reference source not ound.** to **Error! Reference source not found.**). The red bar below the scale shows the targeted change for that year level, and the blue triangle shows the expected level for students at that year level.

Figure 4-5 Transfer of curriculum concepts by Reception level students

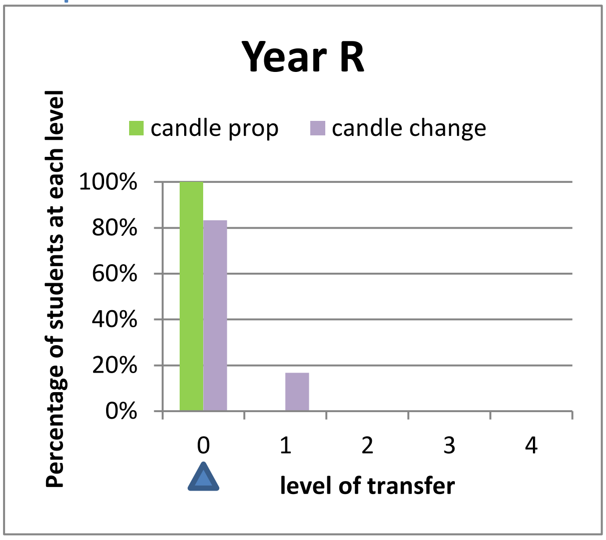


Figure 4-6 Transfer of curriculum concepts by Year 1 students

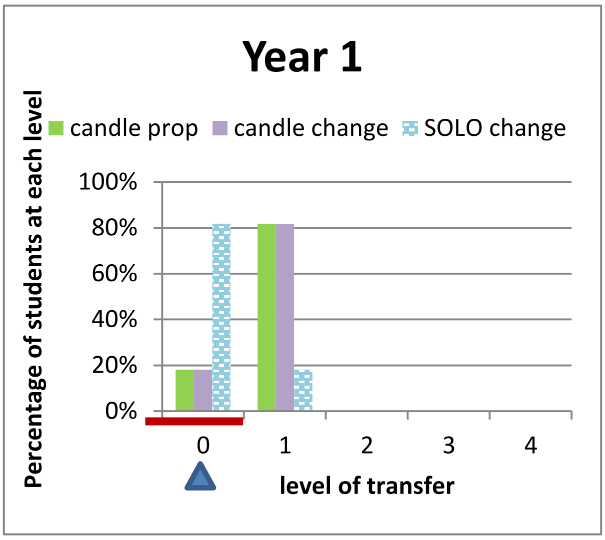


Figure 4-7 Transfer of curriculum concepts by Year 2 students

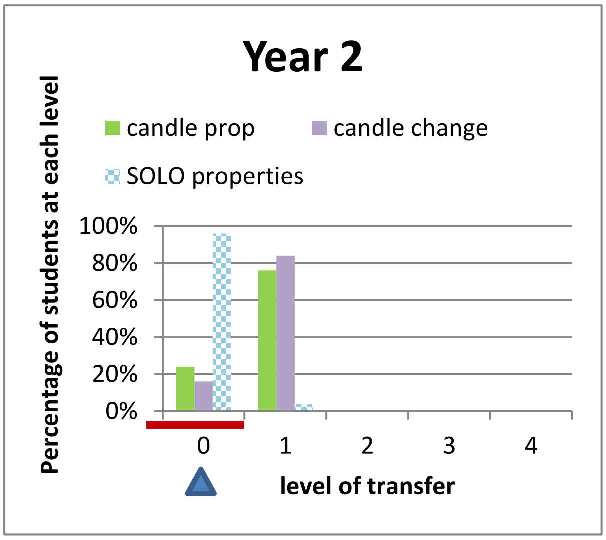


Figure 4-8 Transfer of curriculum concepts by Year 3 students

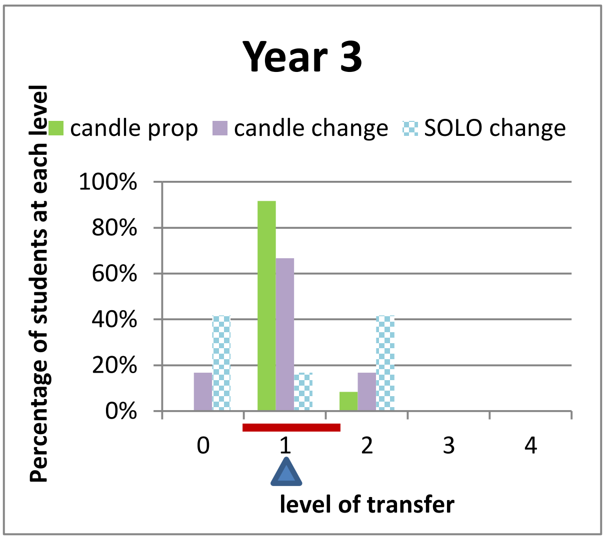


Figure 4-9 Transfer of curriculum concepts by Year 4 students

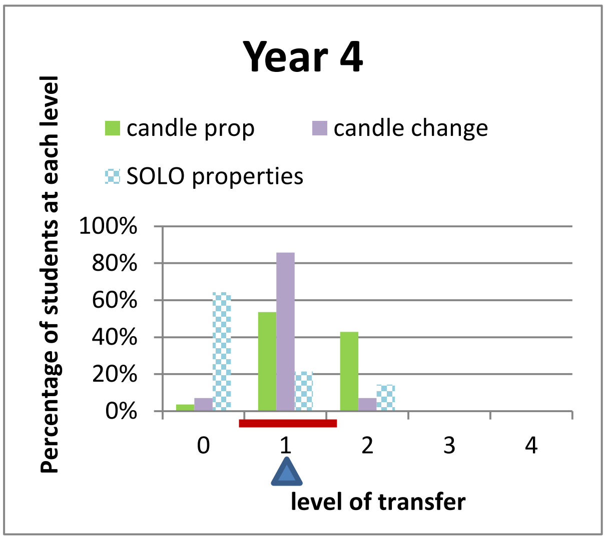


Figure 4-10 Transfer of curriculum concepts by Year 5 students

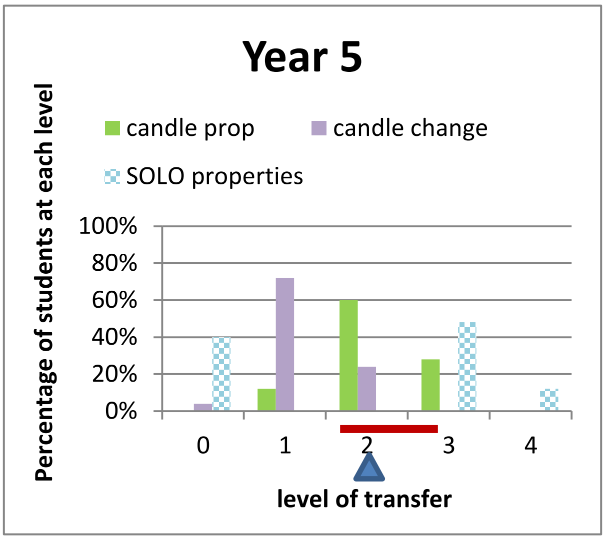


Figure 4-11 Transfer of curriculum concepts by Year 6 students

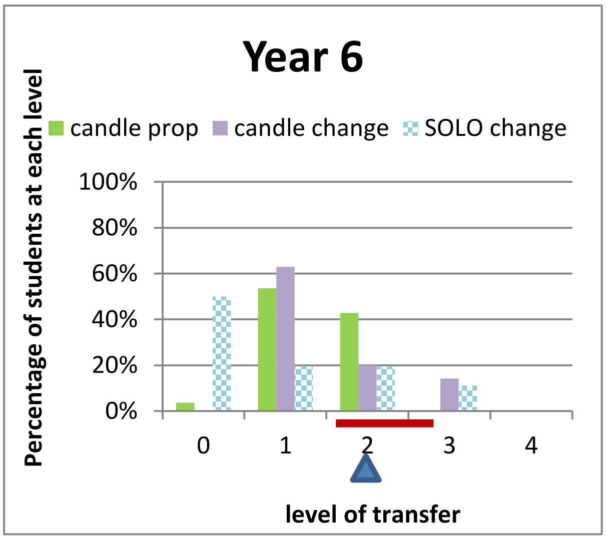
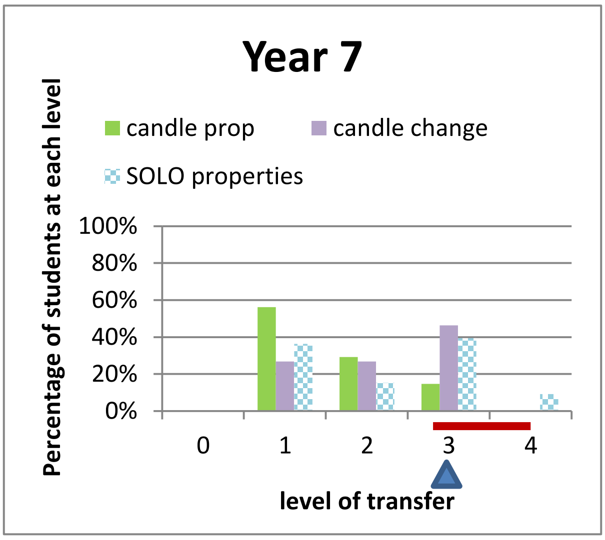


Figure 4-12 Transfer of curriculum concepts by Year 7 students



The charts in (**Error! Reference source not found.** to **Error! Reference source not found.**) map the velopment of student thinking as they progress through primary school. While the progress expected from the curriculum is that they will gain a level of scientific literacy every two years, here, this is not the case for many students. Students in the first three years of schooling are almost universally able to describe single aspects of properties of materials or changes to materials in the concrete context of the candle, but this is not so for students after these years. Although some students in Years 3 and 4 demonstrated the anticipated progress to transferring cause and effect in the candle context: i.e. heat melts the wax, the aluminium is used to protect the table because it does not burn, many remained at the level of describing single aspects. This trend continues in Years 5 and 6, where most students were unable to generalise about properties of gases and types of change but remained at the level of simple cause and effect or describing a single aspect of the candle task.

In the *Explain with example* task (represented by the blue patterned columns), there is little to no evidence that younger students (Years 1 and 2) could engage with the concepts abstracted to changing and mixing materials. In Years 3 and 5, some students showed the targeted thinking with the generalisation task, sometimes in Year 5 relating it to videos about the properties and behaviour of gases that they had viewed in class. However, almost none of these demonstrated this in the candle context. This failure to transfer to another context has been described as inert knowledge (Perkins & Salomon, 2012) – that which is learnt in one context but not transferred to contexts where it might be useful and considered by Chen and Pajares (2010) to be the central problem of education. These students did not invoke the relevant knowledge they had to help them in this context.

The candle task did not prompt students to explain using abstract science concepts, and none did, although, in the *Explain with example* task, a small number were able to do this. Some students in Year 7 demonstrated an ability to generalise in a concrete situation missing in the Year 6 cohort.

Returning to the question of the degree to which the intended learning was transferred in this task, analysis of work samples show that the demonstrated learning lagged behind what could be expected of students and that this gap increased as students moved through the school. NAP-SL, which is run at a similar time of the school year with Year 6 students, expects that 50 % of students will have achieved level 3 after working towards this level for nearly two years(Connolly, 2017). In this task, 50% transfer at the targeted level was only achieved in Years 1 and 2.

In summary, transfer of the targeted learning was above 75% in years one and two and then dropped significantly with requirements to explain and generalise. Transfer of the expected learning was generally higher but followed a similar decline in higher year levels. There seems to be a need to address transfer at Years 3 onwards.

4.4.3.2 How well was the learning transferred.

People transfer knowledge to a context to produce an adaptive response in that context. In work, leisure and community situations, people apply the knowledge they have to achieve outcomes they want. The role of education is to prepare people to transfer knowledge and skills to produce outcomes of benefit to both the students themselves and the community as a whole (ACARA, 2021a)[12]. However, education is a lengthy and multistep process and to measure their progress towards this goal, educators ask students to transfer learning to contexts that have little purpose other than to assess how well prepared the student is to transfer targeted learning to future contexts. Based on the transfer of learning demonstrated, educators may change their learning plan for the student (diagnostic assessment), give feedback to the student on how to improve their learning (formative assessment) or pass on the information to third parties who are interested in how well prepared the student is (summative assessment). Typically the latter includes parents, future educators and future employers, and the information passed on may affect the education and employment options available to the student. Transfer in these tasks is used as a proxy for transfer in the future.

As both employment and further education are competitive, educators are required to give an assessment of transfer that goes beyond simply whether or not students have demonstrated the targeted learning. From Year 1 to Year 12, school reports grade students on a 5 point scale from A to E depending on well a student has demonstrated the learning prescribed in the curriculum (Department for Education and Child Development, 2017b). These measurements of how well students have transferred learning allow employers and educational institutions to rank and compare students selecting those they believe will most likely produce adaptive outcomes in the contexts they are offering. While the curriculum achievement standard specifies the criteria for satisfactory achievement, it is less clear what might constitute below and, in particular, above satisfactory achievement. In transfer terms, the question becomes: What does it look like to be better prepared to transfer this learning?

As well as for classroom educators, this is an issue for those developing assessment materials from individual diagnostic to international assessments. One solution is to set a series of tasks of increasing difficulty and rank students according to the difficulty of the tasks in which they can successfully transfer the knowledge. This raises the question of, given the same concept, what makes one transfer task more difficult than another. Some solutions to this from testing programs and other frameworks relevant to primary school educators in South Australia are shown in Table 4-13.

[12] https://www.australiancurriculum.edu.au/about-the-australian-curriculum/

Table 4-13 The degree of difficulty as measured in South Australian Primary schools

<table>
<tr><th>Testing program/ framework</th><th colspan="6">Least difficult</th><th colspan="6">Most difficult</th></tr>
<tr><td rowspan="2">NAP-SL level (Connolly, 2017) p185</td><td colspan="3" rowspan="2">2. Makes a choice based on firsthand concrete experience and limited application of knowledge</td><td colspan="6">3. describes relationships including cause and effect between individual events reported or experienced</td><td colspan="3">4. explains relationships in terms of an abstract science concept</td></tr>
<tr><td colspan="2">3.1 selects appropriate reason to explain a reported observation related to personal experience</td><td colspan="2">3.2 interprets information in a contextualised report by application of relevant science knowledge</td><td colspan="2">3.3 applies knowledge of a relationship to explain a reported phenomenon</td><td colspan="3"></td></tr>
<tr><td>TIMSS (International Association for the Evaluation of Educational Achievement (IAC), 2013)</td><td colspan="4">knowing</td><td colspan="4">applying</td><td colspan="4">reasoning</td></tr>
<tr><td>Bloom (Anderson, 2001)</td><td colspan="2">Remember</td><td colspan="2">Understand</td><td colspan="2">Apply</td><td colspan="2">Analyse</td><td colspan="2">Evaluate</td><td colspan="2">Create</td></tr>
<tr><td>DOK (Webb, 2007)</td><td colspan="3">Level 1
Recall, basic comprehension</td><td colspan="3">Level 2
Application of concepts and procedures, some mental processing</td><td colspan="3">Level 3
Application with abstract thinking, reasoning and complex inferences</td><td colspan="3">Level 4
Extended analysis and/or synthesis across multiple contexts or non-routine applications</td></tr>
</table>

SOLO (Biggs & Collis, 1982)	*Prestructural* No relevant engagement with concept	*Unistructural* One relevant idea	*Multistructural* Several relevant ideas	*Relational* Links between ideas	*Extended abstract* Ability to generalise and use in new contexts
Department for Education (Department for Education and Child Development, 2017b)	*Minimal achievement* Very basic knowledge and understanding in a few areas of the content, key ideas and concepts. Very limited competence in some of the skills and processes. Beginning ability to use skills and processes in familiar contexts.	*Partial achievement* Basic knowledge and understanding of the content, key ideas and concepts. Limited level of competence in some of the skills and processes. Some ability to use skills and processes in familiar contexts.	*Satisfactory achievement* Satisfactory knowledge and understanding of the content, key ideas and concepts. Expected level of competence in some of the skills and processes. Uses skills and processes in familiar contexts.	*Good achievement* Extensive knowledge and understanding of the content, key ideas and concepts. High level of competence in some of the skills and processes. Uses the skills and processes in some new contexts.	*Excellent achievement* Thorough knowledge and understanding of the content, key ideas and concepts. Very high level of competence in some of the skills and processes. Uses skills and processes in new contexts.
National scientific literacy progress map (NAP-SL 2017)	*Level 1.* Describes (or recognises) one aspect or property of an individual object or event that has been experienced or reported.	*Level 2.* Describes changes to, differences between or properties of objects or events that have been experienced or reported.	*Level 3.* Describes the relationships between individual events (including cause and effect relationships) that have been experienced or reported. Generalises and applies the rule by predicting future events.	*Level 4.* Explains interactions, processes or effects that have been experienced or reported, in terms of a non-observable property or abstract science concept.	

The DECD framework is unique in that it identifies two components of difficulty – the context and the process. Contexts are rated more difficult as they move from familiar to new, although the distinction between familiar and new is not clarified. A context could be:

- familiar in that the learning has been rehearsed in this context before;
- familiar to the student but not in connection with this particular learning, or
- unfamiliar to the student.

Classifying contexts for cohorts of students is fraught with difficulty as it relies on predicting which contexts students may have prior experience. The candle task from which this data was collected was sited in a context that could be expected to be familiar to most students but not one in which they had previously used this particular learning, i.e. a familiar but unrehearsed context. However, there is always the possibility that some students may have no experience with candles, and others might have had experience with them in a lesson on solids, liquids and gases, both of which would affect the task's degree of difficulty.

In terms of the process, recall of memorised information is generally rated as the least difficult, followed by applying concepts, explaining, reasoning, creating or synthesising and generalising. In the candle task, the use of the unrehearsed context removes the opportunity for students to reproduce information from memory. In constructing their responses, students needed to apply previously learnt ideas and were prompted to explain them.

While both test writers and classroom teachers use traditional tests with increasingly difficult items to assess the level of transfer the student is capable of, teachers also use a single task and assess the level of transfer shown in students' responses to this task. This single task is widely used in humanities subjects (e.g. write an essay about …; prepare an argument that …) but is also used sometimes in science and less frequently in maths. The candle task is an example of this form of assessment, and the issue becomes what characteristics of the response might indicate that students are better prepared to transfer their learning to relevant future situations.

Here we stop and consider what transfer of learning, targeted or otherwise, might look like. One way of transferring the concept of using different properties to separate mixtures of materials (Australian Curriculum chemical sciences Year 7) could be to identify that differences in melting points could be used to separate the wick from the wax. To do this, students would need to realise that using this idea in this context might achieve the desired outcome, to read out of the candle context melting point as a property which differs between the wax and wick and apply the idea of melting the wax to remove the wick.

These different elements of conceptual knowledge are described in the coordination class framework (DiSessa & Wagner, 2005) as outlined in Chapter 3.4.1. Classroom teaching and the curricula and syllabuses underpinning them often focus on the functional aspect, teaching students how a concept works. The strategic aspects are often assumed rather than explicitly taught, but knowing the purpose of the context (what you can and cannot achieve by applying it to a particular situation) and as well as when and where it can and cannot be used are very useful in cuing transfer in unprompted situations. When transfer does not happen as expected, it could be that the problem lies with one of these strategic aspects rather than the functional aspects. Thus students who demonstrate both strategic and functional aspects of the coordination class should be well placed to transfer in future situations.

Whether or not these elements are demonstrated depends partly on the task's affordances. The candle task presented the context and prompted the ideas to be used in constructing the response, e.g. properties, uses, change. Some prompts with references such as "solids, liquids and gases" and "reversible" were more specific than others, such as "more information about the parts". Students then used readout strategies to identify these in the context and invoked their causal net to explain them. Their responses provided evidence of the functional aspects – the sophistication of the causal net and the readout strategies in this context. However, most of the strategic thinking has been done for them.

The generalisation task presented them with a generalised statement devoid of a specific context. To explain this statement, students need to use strategic aspects of the coordination class, particularly span and alignment. In explaining with an example, they needed to identify a context where this concept is useful. My suggestion is that students who could do this should be better set up to transfer the concept than those whose knowledge is limited to the functional aspects.

In the following analyses, students' responses were analysed for evidence of higher levels of transfer.

4.4.3.2.1 Reception students

Reception students did not respond to the properties of materials prompt. They used wordless diagrams to convey their observations about how the candle changed as it burnt. Table 4-14 shows the categories and frequencies of their responses to the prompt to record the change in the candle as it burnt. Shaded cells indicate at least satisfactory transfer of the intended learning.

Table 4-14 Responses of reception students to the prompt to show how the candle changed when it burnt.

(Shaded cells indicate at least a satisfactory level)

Code	Properties Thread Response	n	Code	Changes Thread Response	n
			Rca	Indication of change in size and change in wick using before and after diagrams	2
			Rcb	Indication of change in size using before and after diagrams	2
			Rcc	Single diagram indicating a flame	14
			Rcd	Single diagram indicating a change in wick, usually blackening	6
Rpe	No evidence of properties	24	Rce	No evidence of change	0
	total	24			24

Responses Rca and Rcb indicate at least a before and after view of change, with one student recording change as a series of 4 diagrams showing a progressive decrease in the height of the candle. At least a two-stage view of change would seem necessary to understand other changes, e.g. melting. The student who showed four stages in the change in size has made more detailed observations of the change but not necessarily more complex thinking. Responses showing evidence of two different changes show a wider span of the concept of change, which may prepare them better to understand other changes. In SOLO terms, they are multistructural rather than unistructural in recognising change.

Responses Rcc and Rcd show an aspect, flame or wick appearance, of the burning candle but are less clear in how this is a change. It is possible for some students, that their literacy in using diagrams to show change was the limiting factor, so the teacher ran a short session on using diagrams and words to show change. Following this session, the task was redone, and responses included a series of stages in the change, labels and some annotations of students' observations, as shown in Table 4-15.

Table 4-15 responses of reception students after literacy coaching

Code	Properties Thread Response	n	Code	Changes Thread Response	n
			Rca	Diagrams showing a decrease in size and words describing "melting" of wax	5
			Rcb	Combination of diagrams in a series and words indicating at least 2 changes	13
			Rcc	Words and series of diagrams indicating decrease in candle size	2
			Rcd	No concept of change in the same candle. Series of candles with different patterns/ colours. "different candles"	5
Rpe	No evidence of properties	25	Rce	No evidence of change	0
	total	25			25

With coaching in constructing diagrams as described above, 20 students produced evidence of an ability to describe change. Five students used the convention of multiple diagrams but indicated in words that the multiple diagrams referred to different candles rather than one candle at different stages. These students do not have strategic thinking about using diagrams to show change. Many responses used comparative words, e.g. "blacker" or "smaller". Those using the word "melting" have shown evidence of a more sophisticated causal net that will help them develop stage 2 – linking melting to the addition of heat.

For Reception students, the level of transfer shown is highly dependent on the literacy skill of constructing an annotated diagram. Evidence of transfer at a higher level includes multiple different examples of change and using words like "melting" to describe the process rather than separate before and after descriptions.

4.4.3.2.2 Year 1 students

The responses of Year 1 students involved annotated diagrams. Table 4-16 shows the categories and frequencies of their responses. Shaded cells indicate at least satisfactory transfer of the intended learning.

Table 4-16 Response categories of Year 1 students to the candle task

Code	Response to properties prompt	n	Code	Response to changes prompt	n
1pa	Multiple properties	6	1ca	Changes including melting	2
1pb	Single property	3	1cb	Changes other than melting, usually decrease in size, changes in the appearance of the wick	7
1pc	No evidence of properties	2	1cc	No evidence of change	2
	total	11			11

Since they were prompted to describe the parts of the candle, choosing to describe properties is evidence of strategic knowledge of the concept of properties. Likewise, response 1ca is evidence of strategic knowledge about melting. As with the reception students, those students who could identify more than one property should be better positioned to make generalisations about properties in future learning.

Table 4-17 shows the classes and frequency of students' responses to the generalisation prompt. Shaded cells indicate at least satisfactory transfer of the intended learning.

Table 4-17 responses of Year 1 students to the generalised prompt

Code	Response to properties prompt	n	Code	Response to changes prompt	n
1pga	Objects made of materials with properties	2	1cga	Example of a change from candle context	2
1pgb	Definition of a material	1	1cgb	Vague generalisation about changes (e.g. sometimes materials change when you add something)	2
1pgc	Objects made of materials	3	1cgc	No reference to materials changing	7
1pgd	No reference to materials and properties	5			
	total	11		total	11

Engaging with the generalisation by producing examples of materials and properties is transfer of strategic knowledge (span and alignment) and functional knowledge (causal net). The students who provided examples of materials with no properties had a more limited causal net. These examples came from contexts other than the candle with buildings, clothes, cars featuring commonly.

In contrast to the Reception students, for Year 1 students, literacy was less limiting in describing aspects of properties or change. Evidence of transfer at a higher level includes using "melting" to describe a change, identifying many different properties or changes, and using strategic thinking in response to the generalisation question.

4.4.3.2.3 Year 2 students

Year 2 students were drawn from two separate classes, identified as A (Year 2/3 class) and B (Year 1/2 class). Data for Year 2 in Table 4-11 and **Error! Reference source not found.** came from the two combined, but they are considered separately in this section. Table 4-18 shows the categories and frequencies of their responses. Shaded cells indicate at least satisfactory transfer of the intended learning as measured against the A.C. achievement standard.

Table 4-18 Responses of Year 2 students to the candle task.

N(A) and N(B) refer to classes A and B, respectively.

Code	Response to properties prompt	N(A)	N(B)	Code	Response to changes prompt	N(A)	N(B)
2pa	uses of at least 2 materials or components	11	2	2ca	Changes including melting attributed to heat of flame	1	0
2pb	Use of one material or component	0	6	2cb	Changes including “melting”	7	6
2pc	No uses of materials or components	2	4	2cc	Changes with diagram or descriptive indication of melting	2	1
				2cd	Change other than melting	0	2
				2ce	No indication of changes	3	3
	total	13	12		Total	13	12

The properties prompt did not offer the opportunity to transfer strategic knowledge, and evidence of a higher level of transfer lies in identifying two or more different properties. The changes prompt allowed students to transfer strategic knowledge about melting, which many did.

Table 4-19 shows the classes and frequency of students’ responses to the generalisation prompt. Shaded cells indicate at least satisfactory transfer of the intended learning.

Table 4-19 Responses of Year 2 students to the generalised prompt.

(N(A) and N(B) refer to classes A and B, respectively.)

Code	Response to generalised prompt	N(A)	N(B)
2pga	Example of combination of materials for a use	0	1
2cga	Links melting to heat	1	0
2pgb	Examples of different materials from candle task	2	0
2pgc	Examples of materials or properties other than candle task	1	4
2pgd	Evaluation e.g. cool; works	3	1
2pge	SHE about inventors	0	1
2pgf	Repeat prompt	2	2
2pgg	Undecipherable/ not sense	4	0
2pgh	misconception	0	1
	No response	1	1
	total	13	12

Compared with Year 1, more Year 2 students engaged with the generalisation, producing examples of at least part of the concept. Engaging with materials did not require strategic thinking as this was prompted, but even with this prompt, the diversity of inappropriate causal nets shows students attempting to make connections to the generalisation. In these responses, evidence of a higher level transfer included two or more different examples of the uses of materials and the cause and effect explanation of melting by linking it to heat.

4.4.3.2.4 Difference between the two Year 2 classes.

In interpreting the candle context, class 2A demonstrated significantly more ability to suggest uses of materials and to identify changes. However, when this was asked as a generalisation, there was little difference between the two classes.

4.4.3.2.5 Year 3 students

Table 4-20 shows the categories and frequencies of Year 3 responses. Shaded cells indicate at least satisfactory transfer of the intended learning.

Table 4-20 Responses of Year 3 students to the candle task

Code	Response to properties prompt	n	Code	Response to changes prompt	n
3pa	Use linked to properties	1	3ca	Melting linked to heat	2
3pb	Uses of at least 2 materials or components	9	3cb	Melting identified	5
3pc	Use of one material or component	2	3cc	Solids/ liquids identified	3
			3cd	Generalisation about solids and liquids	1
			3ce	No reference to changes	1
	total	12		Total	12

Since they were only prompted to describe the parts, transfer of uses demonstrates strategic knowledge. The student who linked the uses to properties transferred the learning for the following year, a higher level than those who described the uses of the components. Again those able to describe several different uses provide evidence of a higher level of transfer. As melting was not prompted, demonstrating strategic use of the idea of melting and transferring the link between heat and melting showed a higher level of transfer. Some students had readout strategies to locate solids and liquids in the candle context. One student offered a generalisation about solids and liquids with no reference to the context, raising the question of whether this was inert knowledge – previously memorised material cued by the keywords but not able to be applied to the context.

Table 4-21 shows the classes and frequency of students' responses to the generalisation prompt. Shaded cells indicate at least satisfactory transfer of the intended learning. The responses to both prompts are combined.

Table 4-21 Responses of Year 3 students to the generalised prompt.

Code	Response to properties and changes prompt	n
3ga	Heat and change of state in candle context	5
3gb	Change of state no clear link to heat	2
3gc	Rephrase question, no example	5
	total	12

The task offered no affordance to transfer strategic knowledge since the concepts were prompted. Students needed to read out a change of state from the candle context before applying the causal net. Response 3gb indicated that students had read out the change of state but could not apply the causal net. Rephrasing the information given in the question is a strategy used by students hoping that the audience assumes the knowledge that would fill in the gaps. In this case, the gaps were examples illustrating the rephrased concept. More students could relate heat to a change of state in the candle context when given the generalisations than transferred this strategically without the generalisations as a prompt.

At Year 3, evidence of a higher level of transfer included making a connection between materials and properties and providing several different instances of the use of materials.

4.4.3.2.6 Year 4 students

Table 4-22 shows the categories and frequencies of Year 4 responses. Shaded cells indicate at least satisfactory transfer of the intended learning.

Table 4-22 responses of Year 4 students to the candle task

Code	Response to properties prompt	n	Code	Response to changes prompt	n
4pa	Property and use e.g. Aluminium stops fire cos it's not flammable	5	4ca	Links melting to heat	2
4pb	Plasticine holds candle because sticky	7	4cb	Melting to liquid and or properties	6
4pc	Uses of components only	7	4cc	Melting only	12
4pd	Properties only	8	4cd	Describes change other than melting	6
4pe	No response	1	4ce	No evidence of change	2
	total	28		Total	28

Students generally read out properties or uses from the aluminium dish and the plasticine used to support the candle. Their responses seem to have been limited by vocabulary, e.g. plasticine is "sticky" rather than mouldable, and "strong" was used to describe both the inflammable aluminium and the ability of the plasticine to keep its moulded shape. The ability to construct an explanation was also an issue. Both students below are probably making the same point about the aluminium dish being used to prevent fire from spreading because it does not burn, but the second requires more filling in the gaps by the reader.

"To make sure the wax doesn't get everywhere. We use it because it does not catch on fire."

"To not catch on fire because to not burn"

Attempts to relate properties to uses of the wick and the wax featured misconceptions about the role of wax. These are described more fully in the section on misconceptions.

A higher level of transfer was indicated when properties were clearly linked to uses in more than one component.

Table 4-23 shows the classes and frequency of students' responses to the generalisation prompt. Shaded cells indicate at least satisfactory transfer of the intended learning. The responses to both prompts are combined.

Table 4-23 responses of Year 4 students to the generalised prompt

Code	Response to properties and changes prompt	n
4ga	Clear link between materials, properties **and** uses	5
4gb	Examples of materials linked to properties **or** uses	5
4gc	Examples of material, properties or uses	11
4gd	Vague generalisations, rephrasing the question	5
	No response	2
	total	28

The task prompted the strategic knowledge of materials, properties and uses and offered affordance to find examples of these (span and alignment) and explain the links using the causal net. About half of the students took examples from the candle context, and the other half generated their own examples.

As part of the original professional development exercise, the class teacher asked students to respond to individual feedback in the form of a question targeting either the literacy or the conceptual understanding demonstrated in their initial response. The categories and frequencies of these responses are shown in Table 4-24.

Table 4-24 Responses of Year 4 students to the further prompt

Response to further prompt	n
Improved level 1to2	2
Improved level 0to1	1
Same level (2); improved explanation	4
Same level (1); improved explanation	2
Same level (2)	5
Same level (1)	3
Don't know	1
total	18

About half of the students attempting this task produced responses showing no improvement in either literacy or conceptual thinking from the initial response. Only one-sixth managed to improve the conceptual level of their response, suggesting that the conceptual understanding was either not there or not transferred to the candle context for the majority.

At Year 4 evidence, of a higher level of transfer included more precision in language and the use of two or more different instances.

4.4.3.2.7 Year 5 students

Unlike the concepts at other year levels, the Year 5 targeted learning of properties of gases could only be cued in the second part when the candle was alight. Therefore the responses have been sorted into the thread addressed rather than the prompt. Table 4-25 shows the categories and frequencies of their responses. Shaded cells indicate at least satisfactory transfer of the intended learning.

Table 4-25 Responses of Year 5 students to the candle task

Code	Response about properties of gases	n	Code	Response about change	n
5pa	Links property or behaviour to gas	5	5ca	Links melting to heat	6
5pb	Identifies gases around flame	2	5cb	Identifies melting	13
5pc	Identifies fire A(3) or smoke (8) as a gas	11	5cc	Describes a change other than change of state	5
5pd	Reference to properties or behaviours of gases	2	5cd	No evidence of thinking about change	1
5pe	No reference to gases or properties	5		Total	25
	total	25			

Students were prompted to address gases but needed strategic knowledge to include the properties or behaviour in their causal net. Many simply identified smoke (or fire) as a gas, which alone is not evidence of a transfer of the key properties used to classify materials as gases, as it could easily be reproduced from memory. Indication by annotation or diagram that gases spread out through the air was evidence of transfer of key properties, although the quality of the explanations was low. Again the number of students making a clear causal link between melting and heat was low.

Table 4-26 shows the classes and frequency of students' responses to the generalisation prompt. Shaded cells indicate at least satisfactory transfer of the intended learning.

Table 4-26 Responses of Year 5 students to the generalised prompt

Code	Response to properties prompt	n
5ga	Elaborated explanation with particle theory	3
5gb	Explanation with example	3
5gc	Elaborated explanation; no example	5
5gd	Rephrase prompts	3
5ge	Example of a gas	5
5gf	misconceptions	4
5gg	No explanation	1
5gh	No response	1
	total	25

No strategic knowledge of the behaviours of gases or particle theory was demonstrated since they were prompted. Responses identifying an example of these showed span and alignment; others described the causal net in more detail. A high quality response would need to do both.

As part of the original professional development exercise, the class teacher asked students to respond to a question targeting the conceptual understanding demonstrated in their initial response. The classes and frequencies of responses are shown in Table 4-27.

Table 4-27 Responses of Year 5 students to the further prompt

Response to further prompt	n
Detailed elaborating of properties using the language of the video	14
Elaboration of properties using everyday language	4
Examples of gases	5
No relevant response	1
total	24

Here the word "properties" used in the teacher's question cued the majority of students to reproduce the notes they had taken from the video with similar vocabulary, e.g. "compress" and phrasing, e.g. "expand to fill". None of this language or phrasing appeared in the original explanations, probably because it was either rote learnt and not understood enough to be cued by the candle context or the generalisation prompts, or it was not learnt but copied in response to the further prompt. One student's response follows the usual line that gases are easy to compress but reads "gases are easy to combine", raising doubts about how well understood the information was.

Another response illustrates how well students play what they perceive as the classroom game. The teacher wrote on the student's work the question, "Now can you link your knowledge to a real-life example that shows you know gas appears around us?" The teacher's question would have been difficult to interpret, even without the handwritten word "know" looking more like the word "lunar". Without questioning this, the student crafts the response, "Lunar gas is a type of gas. It can be used for some fire places." The student seems to have little expectation that this is about understanding.

There was little convincing evidence of higher level transfer in these responses. Contra indications to higher level transfer include students reproducing material learnt from second-hand sources without the ability to interpret it in this context and students rephrasing the question as a response with minimal input of their own.

4.4.3.2.8 Year 6 students

Year 6 students were drawn from two separate classes, identified as ***A*** (Year 6/7 class) and **B** (Year 6 class). Data for Year 6 in Table 4-11 and **Error! Reference source not found.** came from the combination of these, but they are considered separately in this section. Table 4-28 shows the categories and frequencies of their responses. Shaded cells indicate at least satisfactory transfer of the intended learning.

Table 4-28 Responses of Year 6 students to the candle task

Code	Response to properties prompt	n(A)	n(B)	Code	Response to changes prompt	n(A)	n(B)
6pa	Properties linked to use		4	6ca	Identifies both changes and describes reversing	5	1
6pb	Properties or use	3(1)	19	6cb	Identifies melting and describes reversing	1	1
6pc	Materials only	7(3)		6cc	Describes both changes but no mention of reversing	1	0
6pd	Nothing relevant to properties of materials	1(1)	2	6cd	Describes observed changes; suggests reversing	3	2
	Google assisted (5)			6ce	Describes changes; no mention of reversing	1	19
					No response		2
	total	11	25		Total	11	25

The change thread prompt about reversible and irreversible change precluded students from demonstrating the previous learning about the properties of gases, so the properties prompt reverted to the previous concept of the link between properties and uses at the level below what might be expected. Despite (or maybe because) this being addressed two years previously, there was little evidence of transfer of this concept at level 2, with most students giving single ideas about properties or uses (level 1). There was also limited evidence of transfer of the intended learning for that year, with most responses simply describing change without addressing whether it was reversible or not.

Table 4-29 shows the classes and frequency of students' responses to the generalisation prompt. Shaded cells indicate at least satisfactory transfer of the intended learning.

Table 4-29 Responses or Year 6 students to the generalised prompt

Code	Response to changes prompt	n(A)	n(B)
6ga	Explanation and example of both changes	1	1
6gb	Explanation, no examples		1
6gc	Examples of both changes	2	
6gd	Examples of both changes, misconceptions in explanation	2(2)	
6ge	Examples of one change, misconceptions in explanation		5
6gf	Explanations with wrong terms		2
6gg	Explanation with misconceptions	3	15
6gh	Non example	1	
6gi	Wrong example	1	
6gj	Not addressed	1	1
	total	11	25

The prompt provided an opportunity to apply strategic knowledge of the reversibility of changes. Some responses demonstrated this strategic knowledge but had misconceptions in the causal net. These included associating the terms physical and chemical to the wrong types of change, describing melting as irreversible and associating chemical change with explosions and toxic gases.

In the case of class B, the teacher ran a further activity dealing with physical and chemical changes in making popcorn. This task asked for the same concept in a different context. The worksheet defined physical and chemical changes but did not link these with reversibility. There were affordances to identify melting butter as a reversible and therefore physical change and popping corn as either depending on whether they decided the starch had changed into a different material. Student responses are shown in Table 4-30.

Table 4-30 Responses of Year 6 students in class b to the popcorn task

Response to changes prompt	n
Both types of changes identified with an explanation and correct terminology	4
Both types of changes identified with an explanation but incorrect terminology	13
One type of change correct	4
Misconceptions about classifying change – same change classified as both at different stages	2
Reversibility not addressed	2
No response	2
total	27

In this context, students were more successful in transferring the idea of classifying of changes according to whether or not they can be reversed, although they still had considerable difficulty with the terms physical and chemical. There were some misconceptions about the distinction between a change and a snapshot, with students classifying the before and after stages separately. Some students described rather than classified changes despite the bolding of keywords in the prompt.

Again evidence of higher level of transfer was rare and generally lay in the quality of the explanation, i.e. clear links and precise use of terminology.

4.4.3.2.9 Year 7 students

Table 4-31 shows the categories and frequencies of their responses. Shaded cells indicate at least satisfactory transfer of the intended learning.

Table 4-31 Response of Year 7 students to the candle task

Code	Response to properties prompt	n	Code	Response to changes prompt	n
7pa	Separation - Melt the wax and remove the wick	6	7ca	Correct use of physical and chemical change terms	1
7pb	Separation - Burn the wick which melts the wax and separates it from the wick	5	7cb	Use of chemical reaction/ change term	2
7pc	Separation - Physically break off or remove the wick or put a barrier between the two	3	7cc	Two changes two explanations	9
7pd	Property linked to use	6	7cd	Two changes one explanation	4
7pe	Property or use	8	7ce	Two changes, no explanation	2
7pf	Ingredients plus connections to properties or use	5/5	7cf	One change plus explanation	2
7pg	Ingredients only	8/8	7cg	One change identified	6
			7ch	Misconceptions about changes reversibility	7
	Google assisted (n)		7ce	Description of changes only	8
	total	41		Total	41

The task prompted separating the wick from the wax, so it did not require this strategic knowledge. Of the 34% of students responding to this prompt, only 15% read out the property of melting point and used a causal net to explain how this would work. For the others, this transfer was hindered by a limited view of separation – either that retaining at least one of the materials was not important or that it was enough to move some of the materials apart physically. Those students who did not address the separation prompt responded similarly to those in lower years, addressing either properties or uses, sometimes with a link between the two. In contrast to other years, though, a significant group (32%) appeared to have used their personal tablets to access websites providing details of the materials involved. Typically these refer to the wick as "braided cotton" and list ingredients such as "aliphatic acids", "calcium salts", and "spermaceti". Although some of these students also offered properties or uses, many relied on this for the whole response, opting for second-hand data that did not really address the prompt over making connections themselves. To them, it seems more important to produce a *right* answer than take a risk by generating their own ideas.

In contrast, most students responded to the prompt about the reversibility of the changes. Here the classifying feature of reversibility was prompted, but the scientific terms of physical and chemical were not. Those responses showing transfer of the correct terms (physical and chemical) with the correct changes and explanation showed strategic transfer of these terms, allowing them to add more examples and characteristics of the different types of change. Those who addressed only one change gave no indication that they knew the difference between the two. Those with misconceptions commonly believed that physical changes like melting could not be reversed, focussing on a change in form rather than a change in composition.

Table 4-32 shows the classes and frequency of students' responses to the generalisation prompt. Shaded cells indicate at least satisfactory transfer of the intended learning.

Table 4-32 Response of Year 7 students to the generalised prompt

Code	Response to properties prompt	n
7ga	Links properties to separation technique using particle theory	2
7gb	Links properties to separation technique	12
7gc	Explains mixtures using particle theory	3
7gd	Explains mixtures	1
7ge	Vague or everyday description of mixtures	6
7gf	Mixtures or separation with key misconceptions	10
7gg	No response	9
	total	41

The prompts precluded strategic use of the concept of using properties to separate mixtures, although those making reference to particle theory did show strategic knowledge of this theory. Students appeared better able to do this given the generalised prompt than in the case of the candle task.

However, as with the responses from the first two parts of the candle task, the language and consistency of many of the responses indicate that they may be heavily reliant on information from websites. Responses such as:

"A pure substance cannot be separated into 2 or more substances by physical or mechanical means"

"Chemists use filters called zeolites which have holes so tiny …"

seem to be direct quotations from websites. Together with the appearance of identical supporting diagrams, they suggest that transfer was limited to the ability to use a search engine and identify and reproduce relevant information. This is a problem with generalisation questions – responses can be reproduced from other material or rote learning without understanding the concept's elements or the connections between them. The apparently adaptive response in the context of the moment is not necessarily a good indicator of transfer in different future contexts. One way to minimise this is to include explanations in contexts that could not be searched for as easily.

4.4.4 Discussion

4.4.4.1 Indicators of higher level of transfer

In this series of tasks around the candle, the common context and prompts often precluded students from showing evidence of transfer of the strategic elements of the coordination class and the question is how well the functional elements of readout and causal net were transferred. Evidence of high level transfer of functional elements shown by these students included:

- a range of different instances of the concept, e.g. several different properties, uses, examples compared with one single example;
- explanation or comparison, making clear links between the components rather than separate observations or ideas.

It could also include:

- comparison of the instances identifying the key relevant features; and
- generalisation from these instances rather than a reproduced formula or definition.

In the generalisation task, higher level transfer looked like explaining the generalisation with reference to several different examples from the current or self-generated contexts. It did not look like reproduced material from second-hand sources, and given the ubiquitous availability of these in digital form today, this can be difficult to identify. In addition, students who have been coached to 'have a go' at questions may have amassed a range of strategies for producing a response with little understanding. In these students responses, there was evidence of students rephrasing the question with minimal input and generating vague examples couched in indefinite language such as *may* and *some*.

4.4.4.2 Implications for task design

While the single context task with an expanded response offers an alternative to the test with multiple limited response items, it does come with its own limitations. Two particular challenges are discussed here.

The first involves constructing and presenting prompts to allow differential access to students capable of showing different levels of transfer. In this task, these prompts were presented in a series above a single response space, and many students did not engage with more than the first. Getting students to read and respond to the question asked is always a challenge, but even more so when there are multiple parts to the prompt. While these are useful to release cues in stages and increase the challenge, they need to be in a format with separate response spaces for each prompt or at least a way of identifying the prompt to which the response belongs. Digital technology would be very suited to presenting these.

The second is about allowing for transfer of strategic as well as functional elements of the concept. Very open prompts leave the student guessing as to what concepts are useful. On the one hand, this is what we want as it enables students to show strategic knowledge by identifying adaptive concepts. However, problems arise when there is more than one adaptive concept depending on the direction in which the responder chooses to head. Some students in Year 5 described the candle properties in terms of information available to blind people, describing how spirals would allow them to identify the candle by feel. Others associated the spirals with providing a channel for the wax to run away from the top of the candle. If the prompt had been "describe and explain what is happening as the candle burns", then students who used ideas like properties, uses, gases, changes in their responses would have provided evidence of strategic knowledge. However, those who did not have the strategic knowledge or went in a different direction would not have shown evidence of the function aspects either. Again, the sequenced release of prompts could address this, and again, this is easier to organise in digital rather than paper format.

To minimise opportunities for students to reproduce rote learnt material or material from other sources as evidence of learning, questions need to require students to interpret generalisations in a context – either supplied by the task or chosen by the students themselves. While it is still possible for students to rote learning application in a context, it is less likely given the greater memory demands.

4.4.4.3 Non-adaptive transfer – Misconceptions

Although students were not asked to explain how the candle works but rather use it as a context to identify instances of a range of other learning, their responses show a plethora of thinking about the working of a candle. This section looks at the frequency and sequence of some of these.

The purpose of teaching science in schools is to equip students with the thinking of western science so that they have this as a tool to use adaptively in their "personal, social and economic lives", according to the Australian Curriculum Science Rationale (ACARA, 2021a). Rather than science process (observing, noticing, questioning, predicting, collecting data and interpreting data), this study focuses on the understanding that underpins these and equips people to explain observations, justify predictions and critically evaluate conclusions. Students from the eight years spanned in this study show varying degrees of progress towards this. Not all responses are consistent with western science thinking, and here, these are referred to as misconceptions while still acknowledging that to the student producing them, they were the best available thinking at the time. Some misconceptions fly in the face of western science and will not help in establishing the targeted thinking (e.g. *wax doesn't burn),* while others are partially correct (e.g. *wax shrinks)*. The latter responses are referred to here as limited conceptions. According to Ohlsson (2011) p 367 table 11.1, the latter can be simply extended with new learning, whereas the former must be conceded as a dead-end and overwritten by new learning.

A range of observed misconceptions and limited conceptions related to the burning candle are shown in Table 4-33. They are sorted by which part of the candle they deal primarily with. The first group in each section are observations, while the second are interpretations – connections between an observation and some prior thinking. Shaded cells identify misconceptions, while non-shaded cells identify limited conceptions.

Table 4-33 Misconceptions and limited conceptions shown by students R-8 in the candle task.

	Thinking	Year/ class								
		1	2a	2b	3	4	5	6a	6b	7
Related to the wick	Wick is the part the fire goes in	3		10	3		1		7	
	Wick is where it is lit	6	9	2	3	7	10	1	7	
	Wick stays up						1			
	Wick gets bigger		2			3	1			
	Wick looks like it's getting bigger					1				
	Wick is (like) a fuse				1	2				
	Wick is flammable					13	4	2	6	
	Wick helps the candle burn				1	1			1	
	Wick makes the candle burn faster							3		
	Wick makes the candle last longer/ keeps it going						1	3	1	
	Wick melts the wax so it burns				1					
	Wick burns						4	2	4	
	Wick does not burn						1			
	Wick stops the candle burning					1				
	Wick stops the fire melting the wax					1				
	Wick makes flame higher and smaller							1	1	
Related to wax	Wax shrinks					1				5
	Wax melts					3	7	2	2	12
	Wax is strong					1			2	
	Wax makes the fire keep going	2		2		6		1	1	
	Wax makes it burn longer				5	5	1		1	
	Wax helps the flame burn			1						
	Wax makes it get on fire	1								
	Wax used to hold/support the wick	3	2	5	2	4	4	2	7	
	Wax keeps the fire off the foil		2		1	1			1	
	Wax melts to make it burn				1					
	Wax melts, heat makes chemical reaction					1				
	Wax burns	1				2	2		1	
	Wax melts due to heat									14
	Wax melts and vaporises due to heat									7
	Wax is a fuel								4	
	Wax can have a scent								4	
	Wax doesn't burn		3		1		11	1	3	
	Wax doesn't burn easily					2				
	Wax stops the flame spreading				1		1		2	
	Wax doesn't melt						1			
	Wax stops the fire after the wick has gone out							2		
	Wax stops all of the wick burning								2	

	Thinking	Year/ class								
	Wax dries									1
	Melting wax can't be reversed									4

Curriculum demands of students in the first three years of school are primarily concerned with observing, and Table 4-33 shows that these were generally accurate. One exception to this was the foundation students who, after observing a plain coloured candle, decorated their diagrams with multi-coloured patterns. How limited conceptions lead to misconceptions can be seen in their observation that the wick gets longer. One Year 4 student explained that it gives the appearance of getting longer as the wax melted away.

A burning candle is challenging to explain as it relies on an understanding of change of state from solid to liquid and to gas, capillary action and burning as a combination of wax vapour with oxygen, most of which cannot be directly observed. Across the year levels, students' attempts to make sense of this concept can be seen in their responses, beginning with direct observation that the flame is associated with the wick, which chars and the wax melts and disappears. Combined with their firsthand experience of burning, students suggest that the wick burns and the wax serves to support the wick as it burns, allowing people to hold it. Ignoring the observation of the disappearing candle wax, they inaccurately conclude that because the wax melts, it does not burn. Some students in Year 3 or above suggest that the wax somehow facilitates the burning of the wick, some Year 7 students state that the disappearing wax has vaporised and spread into the surrounding air. Only five students provided evidence that they had made the connection that it is the wax that's burning and melting is part of that, although no student was able to interpret the purpose of the wick as to generate a mixture of oxygen and wax vapour that continues to burn in a controlled way.

Students' misconceptions about science concepts have been researched for some time. A classification in five categories based on how the misconception developed was outlined by the United States Committee on Undergraduate Science Education (*Science teaching reconsidered a handbook*, 1997) and continues to receive attention, particularly from researchers working with tertiary students, e.g. Paulick, Retelsdorf and Möller (2013), (Suprapto, 2020). An alternative hierarchical scheme proposed by Chi (2013) and adopted by the University of Melbourne in their handbook on student misconceptions (Verkade, Mulhern, Lodge, Elliott, Cropper, Rubinstein, Horton, Elliott, Espinsos, Dooley, Frankland, Mulder, & Livett, 2017) uses a different approach, classifying misconceptions on their difference from the science concept. Using this scheme, educators can use evidence from student demonstrations of learning to identify the kind of misconception rather than needing to suggest how it originated. Both schemes come with implications on how educators should leverage different kinds of misconceptions to optimise student learning.

From an educator's point of view, misconceptions and limited conceptions are evidence that students are trying to explain their observations by making connections to ideas they already have. Ohlsson (2011) p 367 distinguishes conceptual changes where learners add on to the limit of their existing knowledge (monotonic change) from those requiring learners to override and replace existing knowledge (non-monotonic change). The latter correspond to the flawed mental models and category mistakes of Chi's classification and can be resistant to change, even after direct instruction (Hattie & Yates, 2014) p 48. Despite having the concepts of western science explained to them, many students fall back on their previously held ideas, e.g. that the sun is closer to the earth in summer; candle wax melts but doesn't burn. Ohlsson (2011) p353 proposes a process of competitive evaluation between conflicting conceptions analogous to natural selection in ecology, in which those beliefs which have proved useful in the past are retained. To counteract these, students need a lot of evidence of the usefulness of the new beliefs. This evidence could be assembled from practice in making sense of new contexts where the old beliefs do not work, but the targeted concepts do. Benefit from practice also applies to limited conceptions where vocabulary was the limiting feature, e.g. "strong" used to mean inflammable, able to keep its shape; and "dries" used to mean solidifies. Students need the ambiguity of their use of these words challenged and practice in using more precise vocabulary.

In that they indicate students' attempts to make sense of context, misconceptions are a useful starting point for educators. They indicate what must be challenged and what must be refined, and ignoring them is like firing blindfolded at a target. One of the benefits of well-run class discussions is the opportunity for all students to learn from the misconceptions surfaced.

4.4.4.4 Who is doing the transferring?

4.4.4.4.1 Group and individual transfer

Even though students were required to produce individual written responses, the materials for this task were generally shared between two students sitting at the same table. There was conversation between the students in all classrooms as the task was completed. Some tables were arranged into groups of two (four students), and conversations extended to students beyond their immediate table partner. The degree of sharing of ideas is reflected in the similarity between responses. Unique responses had no noticeable similar elements to others in that class, although they may have expressed similar ideas. Responses with common elements had slabs of similar ideas expressed using similar phrasing, diagrams, or layout. These typically started similarly and then diverged part way through as the students worked at different paces. Occasionally they had unique responses to the candle task but similar responses to the generalised prompt. Responses classed as identical (+ extra) were almost identical in wording, layout and diagrams, but one student elaborated more than the other. This suggests the two students worked in close collaboration, but one recorded less because they could not keep up or chose not to record as much. Finally, some responses were almost identical in every respect, often occurring in students relying on a website for their responses. The distribution of these across the classes is shown in Table 4-34.

Table 4-34 Similarity in responses across classes

Year	n	Unique	Common elements	Identical (+ extra)	Identical
F					
1	11	2 (18%)	1x2; 1x3 (5 – 45%)	2x2 (4 – 36%)	
2a	13	7 (54%)	1x2 (2 – 15%)	2x2 (4 – 31%)	
2b	12	8 (67%)	1x2 (2 – 17%)	1x2 (2 – 17%)	
3	12	10 (83%)	1x2 (2 – 17%)		
4	28	15 (53%)	4x2; 1x3 (11 -39%)	1x2 (2 – 7%)	
5	25	21 (84%)	1x2 (2 – 8%)	1x2 (2 – 8%)	
6a	11	7 (64%)		1x2 (2 – 18%)	1x2 (2 – 18%)
6b	25	23 (92%)	1x2 (2 – 8%)		
7	41	17 (42%)	7x2 (14 – 34%)	2x2 (4 – 10%)	3x2 (6 – 15%)

Across Years 1 to 7, 38% of students produced responses showing some degree of similarity to those of others.

There are different interpretations of similar responses. At their best, they result from students collaborating by sharing observations and prior knowledge, challenging each other’s thinking and constructing a joint statement on their current understanding. At their least productive, one student’s thinking is copied verbatim by another, or both students copy verbatim from a second-hand information source such as a website. Two distinct questions could be asked about similar responses.

Firstly, to what degree does this response provide evidence of this student’s capacity to transfer this concept to future learning in a different social group? This question is asked when assessing individual students, as similar answers make it difficult to interpret whether the capacity to transfer lies with one, both or neither student. In cases where an individual assessment is required, such as reporting to parents or ranking students for admission to competitive programs, similar responses may not provide useful evidence without other measures.

Secondly, to what degree does this response represent evidence of this student's cognitive involvement in learning this concept? Educators ask this question as they plan the future learning experiences of the class. It has similarities with the concept of legitimate peripheral participation (Lave & Wenger, 1991), which describes the socially situated process whereby newcomers to a group participate on the periphery while they learn the skills of the group experts, over time increasing their skills towards acquiring expert status. The process is commonly described as an apprenticeship. In the classroom, rather than newcomers and old-timers, there are students at different stages in their understanding of the concepts. A student working at a higher level (the expert) may model transfer of concepts for another (the apprentice), thus increasing the capacity of the apprentice to do this. For this to happen, there needs to be active cognitive engagement with concepts rather than mindless copying, and the more advanced student needs to be working at a level that is within the resources of the other to reach. Incidentally, the expert may also develop their understanding if challenged to explain by the apprentice. Once again, similar responses do not provide evidence of the degree to which the apprentice has improved their ability to transfer. However, while similar responses do not allow educators to individually tailor learning experiences, they have some use in planning learning experiences for the group, including providing misconceptions and limited conceptions for class discussion.

The reliability of information obtained from similar responses is questionable in both scenarios. This reliability may be improved by asking supplementary reflection questions about the learning process and outcomes, requiring students to work with different partners in different tasks and observing the students as they construct the response. Conversation and collaboration between pairs of students is a common occurrence in many primary classrooms, to the extent where enforcing individual answers for standardised testing like NAPLAN can be challenging for both students and teachers. Another approach to this issue of reliability from similar responses is to bring students into the discussion on how similar responses support or limit learning and assessment and identify times when they are and are not appropriate, including times beyond the control of the students and teacher.

The problem of students producing joint responses is also an issue for pencil and paper-based standardised testing and has been largely ignored. Some tests produce booklets with questions in different orders so that students are less likely to be looking at the same page at the same time. Testing in digital format with its capacity to adapt the difficulty of questions to students' previous responses also reduces this as an issue. The other consideration is the potential effect of stress on students required to produce individual responses with little experience in this or who do not have the literacy skills to produce a response that does justice to their knowledge.

4.4.4.4.2 Google assisted transfer

The other issue around similar responses involves the reproduction of second-hand information from sources such as websites. In today's world, this information is easily accessible, especially in upper primary, where many students have personal devices at hand throughout the school day. Searching is easy, providing an instantaneous array of information about many concepts. Once again, in a best-case scenario, websites may provide structured information that students relate to the context at hand and use to extend their understanding of the concept. At the other extreme, students search for a keyword and then mindlessly reproduce information from the screen. This reproduction without understanding was seen in the responses of Year 7 students who reproduced lists of the ingredients in candle wax or plasticine, ignoring the prompt about separating the wax from the wick.

To avoid mindless copying and plagiarism, teachers often urge students to put the information into their own words in the hope that students will make sense of the information, incorporate it into their understanding and re-represent it as they see it. Unfortunately for some students, this could be asking too much of their combined literacy and conceptual understanding, and what they transfer is the ability to restructure sentences and find synonyms for terms to make the response sufficiently different from the original.

Once again, a strategy to address this could involve bringing students into the discussion about how simply locating and reproducing information is a skill of limited use and constructing, explaining and justifying a response to a particular question is the ultimate aim. For some students, this may be a considerable change of direction.

4.4.4.5 Literacy and transfer

The candle task involved literacy in both receptive and productive modes, as students needed to understand the task and then construct a response. This section considers how their literacy levels in doing this might have affected the level of transfer of the science concepts they were able to demonstrate.

The task was presented as text and diagram, accompanied by an oral explanation from the teacher and the opportunity to ask questions both in the whole class group and individually once students had started work. Tasks for students in levels up to Year 3 generally had relatively simple prompts to *describe*, and students generally did this to a satisfactory level according to the achievement standard, but as the prompts got more complex after Year 3, more students seemed to miss the point. Prompts were often presented in a series of two or three and some students did not go past the first. The most striking example of this was in Year 7, where students were asked first to add annotations to give more information and then to explain how to separate the wick from the wax. Only one-third of Year 7 students addressed the second part of the prompt. Implications for task design have already been discussed earlier, but there are also implications for pedagogy in teaching students how to read questions so that they answer what was actually asked.

It seems that the ability to construct a response may have been a limiting factor, and this starts early. Reception students produced wordless diagrams to show the change in the burning candle at their first attempt. When the task was repeated after literacy input, they produced a series of labelled diagrams with some annotations. When the requirement was a description of a single aspect, over 80% of Year 1, 2 and 3 students could do this. However, once the prompt required connecting ideas to produce explanations, demonstration of transfer of the science concepts dropped off. Many students recorded a few keywords or relevant phrases that relied on the reader to sequence these into an explanation. In these cases, giving students credit for understanding makes assumptions about the connections intended.

Some literacy conventions were more productive in communicating understanding than others. Expressing ideas as dot points tended to limit students to single ideas rather than connections, but using tables allowed comparison as in the case of reversible and irreversible changes. In constructing a response, students needed to transfer a literacy convention that allows them to demonstrate the transfer of the science concept, and for some students, this became a limiting factor as the demands of the transfer task increased.

Another limiting aspect of literacy appeared to be students' vocabulary, including but not limited to scientific terms. As an example, many students in Year 4, but also other levels, used the word "strong" to variously refer to the aluminium being inflammable, plasticine keeping its shape and solid wax being hard, which makes it difficult to demonstrate the link between the properties and their use in the candle set up. Year 6 and some Year 7 students who attempted to use the terms physical and chemical to classify changes showed significant confusion about how they related to reversible and irreversible changes. In the Year 6 follow up task, 13 students associated the terms physical and chemical with the wrong type of change compared to 4 who used the terms correctly. As well as communicating, scientific terminology supports precision and clarity in thinking by providing a widely understood label for a category characterised by similar features. Without the label, students would have to juggle lists of features of categories in their thinking and responses.

Issues around students' literacy need to be addressed by teachers during the learning phase and in assessing student transfer of the learning. It seems likely that transfer would be supported if relevant vocabulary and skills in writing explanations were taught alongside the science concepts. Transfer might also be supported if assessment tasks were designed to minimise the effect of literacy limitations on students' ability to demonstrate transfer.

4.4.5 Conclusion

4.4.5.1 What did they transfer?

4.4.5.1.1 Targeted learning

Transfer of the targeted learning was above 75% in Years 1 and 2 and then dropped significantly with requirements to explain and generalise. Transfer of the expected learning was generally higher but followed a similar decline in higher year levels. There is clearly a need to address transfer of science concepts from Years 3 onwards. There is also evidence of inert knowledge cued by generalised prompts but not used in contexts where it would have been useful. Strategies such as experience with concepts in multiple contexts might address this.

4.4.5.1.2 Levels of transfer

Transfer at a higher level was identified as transfer that is evidence of the learner being better equipped to transfer this concept in the future. In this task, evidence of higher level transfer included multiple different instances of the same idea and clarity and precision in explanations linking ideas. There was limited evidence of this, and future classroom programs would need to make these expectations clear to students and develop their ability to deliver them.

4.4.5.1.3 Misconceptions

The responses identified a range of misconceptions about the process of a burning candle. In younger students, these tend to be naïve and based on the most obvious observations, and in the best-case scenario, these evolve to become closer to western science explanation as students realise their limitations. Unfortunately for some students in the later years of primary school, there was evidence that these misconceptions existed in pretty much the same form as in earlier years. Challenging misconceptions may be a powerful teaching strategy for developing depth of understanding.

4.4.5.1.4 Someone else's thinking

Just under 40% of students across Years 1 to 7 produced responses showing a high degree of similarity, so potentially up to 20% of students were not engaged cognitively in the task. The implications for these students include not developing a deep understanding of the concept, no access to tailored feedback and no experience at being individually accountable for their responses. If this occurs regularly, then situations where individual responses are enforced, such as standardised testing, could be bewildering and stressful experiences. Similar issues arise in classes where students have ready access to internet-enabled devices, and the response produced may represent the thinking of the author of a website.

4.4.5.1.5 Literacy skills

The literacy skills needed to access the prompt and construct a response appeared to be a limiting factor for many students. These included the ability to respond to multiple prompts, the disposition to use writing to supplement drawing in Reception students, and the use of precise vocabulary and construction of clear explanations by middle and upper primary students. Addressing literacy alongside science concepts is one strategy to maximise transfer of science concepts.

4.4.5.2 Implications for research on classroom strategies to improve transfer

The analysis and interpretation in this study were conducted to inform how research could help interpret data on student transfer of science concepts. Here the emphasis is reversed; how this data might inform research becomes the focus.

4.4.5.2.1 Factors related to the learning experience

Because this study used work samples generated for another purpose, namely teacher professional development, there was no information about the learning conditions in which the targeted concepts had been learnt. This gap was addressed by the research described in Chapter 5.

In this study, occurrences of learner-generated multiple instances of a concept were seen as evidence of a higher level of transfer. It would seem that to maximise transfer of a concept, it should be experienced in multiple contexts as it would support learners in identifying the key aspects of the concept readout independently of all other aspects of the context. This experience would contribute to developing a succinct readout strategy and causal net, devoid of context, that could be overlaid on a range of other contexts. Indeed, there is evidence that generalisation from multiple contexts improves transfer (Sternberg & French, 1993, p. 35). This raises questions about integrated approaches that teach science concepts in the context of a real-world problem and suggests that other instances of the concept should also be experienced. Experiencing the learning in multiple contexts would also address the issue of students memorising generalisations but being unable to see them in other contexts (inert knowledge).

The nearly 20% of students in this study who reproduced someone else's thinking missed the opportunity to engage with productive struggle. Productive struggle requires learners to search for solutions in contexts before presenting the concept (Richland et al., 2012; Warshauer, 2015). It is thought to increase students' cognitive engagement with the concept by requiring them to actively generate and test a range of ideas, including misconceptions, rather than mindlessly enactor a pre-learnt process. The productive part comes in the debriefing when students consider the effectiveness of various ideas and decide on which was most adaptive in that context. Productive struggle prompts need to be carefully crafted to require new thinking that is within range of the learner's current resources.

There was little evidence of students' strategic thinking in the Explain with example task. Lack of strategic knowledge about a concept is also a significant issue in multiple question tests, requiring students to select learning to use in a range of contexts. Engle (2012) describes expansive framing as framing the learning as relevant to a wider range of contexts than that in which it is taught. Thus expansive framing has similarities with the generalisation from multiple contexts described above but distinguishes between the functional and strategic aspects of the knowledge. Both aspects could benefit from generalisation from multiple contexts. However, while productive struggle is often limited to generalising the functional aspects (what to read out and how to apply the causal net), expansive framing generalises the strategic aspects (when and where to use it and what can be achieved by using it). The cuing of concepts in the first two parts of the tasks used in this study often precluded the demonstration of strategic aspects of the knowledge, which serves as a reminder that at least some tasks should provide an opportunity to demonstrate transfer of strategic aspects of concepts.

4.4.5.2.2 Factors related to the students themselves

The prevalence of misconceptions in students' responses is a reminder that a framework to describe transfer should distinguish these from limited responses. In order to develop transfer of the targeted concept, misconceptions need to be specifically addressed rather than ignored.

Students' literacy skills in interpreting prompts and constructing responses need to be addressed in two ways. Firstly, presenting the prompt and providing options for responses should be done in a way that minimises the impact of inadequate literacy skills. Secondly, attention should be given to developing the appropriate literacy skills alongside the science concepts, which may have benefits in improving students' communications and their capacity for clarity and precision in thinking.

Finally, like literacy, students' dispositions may limit both their engagement with the concept and the degree to which they communicate their thinking. The effect of dispositions like those outlined by theory of intelligence, goals and mindset researchers has been documented in research (for a review see (Dweck & Yeager, 2019)). Measuring student dispositions would add another layer to the transfer of science concepts in new contexts.

5 Experiments investigating the impact on transfer of a range of factors

5.1 Overview

The qualitative analysis of existing evidence of students' transfer of science concepts reported in Chapter 4 suggested a range of factors related to the transfer task and the learners that might affect transfer. However, no conclusions could be drawn about the impact of different learning experiences as there was no information about the students' learning experiences. To investigate this category of factors, two experiments were carried out. The research questions addressed were:

- How do factors relating to student's learning experiences (specifically a pedagogy of expansive framing and productive struggle) affect transfer of science concepts?
- How do these factors interact with other factors related to the concepts learnt, the way transfer is measured and the students' dispositions?

The results are reported in the following two sections.

1. *A pilot study of the impact of pedagogy.* Materials were developed to test the impact of a combination of factors related to pedagogy on transfer, and a pilot study of these was carried out with three classes of Year 5 students. This study was primarily quantitative, with some qualitative data collected from teacher and student participants, and its main purpose was to test the learning materials under field conditions.
2. *A field study of the impact of low and high challenge pedagogy*. In the light of findings from the pilot study, a set of materials was developed to investigate the impact of pedagogy in a larger field study. This quantitative study with a quasi-experimental design involved a more participants. In addition to transfer, a range of other variables related to the student dispositions and prior knowledge was measured. As well as the quantitative data, qualitative data related to student and teacher perceptions of their teaching and learning experiences were collected.

Findings from these two experiments were integrated to consider the implications for educators of interactions between a range of factors related to the learning experience, the learners and the conditions of transfer. Together they contribute to our understanding of transfer of science concepts by different students in different circumstances.

5.2 Classroom strategies to support transfer – a pilot study

5.2.1 Introduction

The studies of artefacts and documents related to students' classroom transfer of science concepts described in Chapter 4 have suggested that factors relating to the learning content, the transfer task and how transfer is measured affect the transfer of science concepts by students in Years 4 to 6. However, there was no associated data on the conditions under which the concepts were learnt or students' prior knowledge before the learning. Learning conditions, including teacher pedagogy, are particularly relevant to educators as these are factors over which they have some control.

One particular dichotomy in pedagogy is the distinction between explicit teaching and inquiry-based learning, and among educators, there are enthusiastic supporters and critics of each (Anderson, Dewhurst, & Nash, 2012; Kirschner, Sweller, & Clark, 2006; Kruit et al., 2018; Tytler, 2019). While there is some common understanding about how these pedagogies are implemented, to a degree, they are open to interpretation by practitioners. Classroom implementation of these pedagogies could be investigated by a qualitative study of pedagogy in several classrooms with a focus on the key features of each. Such a study may give insight into the impacts of different combinations of factors, although it is not as useful in identifying the impact of individual factors.

An alternative is to search for existing studies involving key distinguishing factors of these pedagogies to select a small number of promising factors to follow up in a classroom investigation. The literature review in Chapter2 Section 4 of this thesis found that existing research falls into two categories. There are those investigating relatively generic classroom approaches, such as expansive framing (Engle, 2006), explicit instruction (Kruit et al., 2018) and productive struggle (Warshauer, 2015), which have the potential to be applied to a broad range of learning content and classroom activities. By contrast, others are focused on a specific classroom activity that might be an example of one of the more generic strategies. These specific classroom activities include tactics such as inventing with contrasting cases (Schwartz et al., 2011), spaced quizzing (McDaniel et al., 2013), and regular self-assessment (Bernacki et al., 2016). This study focuses on generic classroom strategies rather than particular activities as these maximise the potential for generalising to a range of classroom situations.

From the literature reviewed in Chapter 2, the following three strategies showed potential, at least under laboratory conditions, to support transfer:

Expansive framing has been shown to improve transfer (Engle et al., 2012). Framing refers to how the learning is positioned in relation to the learners' lives and experiences, addressing the strategic knowledge of the concept or the question: *What is this learning for?* Framing can be bounded, where it is tied to the education situation in which it is learnt – the subject, class, teacher, classroom, school term, or expansive, where it is sited in a wider context. The latter may include future learning, work and everyday life. In participating in a school class, students are usually aware of the bounded framing for learning, but there may be considerable variation in how much they engage with expansive framing.

In the states of matter example used in Sections 1, 2 and 3, this would look like the difference between:

Bounded framing: This term, we are learning about solids, liquids and gases because it is in the curriculum and will contribute to your grade.

Expansive framing: This term, we are learning about solids, liquids and gases as a way to classify matter in our world because it will help explain and predict how materials might behave.

Productive struggle refers to a strategy to support student engagement in active meaning-making (Richland et al., 2012; Warshauer, 2015). Traditional classroom pedagogy commonly involves a *tell and practice* approach, where access to the concept is provided by face to face explanation, textbook, multimedia or a combination of these, followed by opportunities to practice applying the concept. The opportunities are often graded in increasing difficulty or decreasing scaffolding. This methodology is expected by many students and parents and is designed to reduce cognitive load at each step, avoiding failure and the consequent challenge to confidence and self-esteem. An alternative is known as productive struggle (with strong links to productive failure (Kapur & Bielaczyc, 2011) or desirable difficulties (Bjork et al., 2014)), where students engage with a task requiring the targeted learning, but without prior cuing or scaffolding of the learning. The role of the teacher here is to support their struggle by clarifying thinking or suggesting metacognitive processes rather than to scaffold the application of the concept directly. The struggle to come up with a solution may involve activities such as individual and/or group discussion; self-driven access to resources and/or generation and evaluation of multiple solutions, but the second key aspect of this methodology is that after struggling, the concept is presented to learners and opportunities given for them to compare it with their thinking. At this stage, teachers can have a direct teaching role.

In the states of matter example, this might look like:

Tell and practice: teacher explains the differences between the properties of solids, liquids and gases, and students use them to classify samples;

Productive struggle: students classify samples in as many ways as they can think of, possibly including solids, liquids and gases and then the teacher introduces science classification and asks: How does your classification compare with the science version?

Generalisation from multiple contexts has been shown to be important in analogical transfer (Goldstone & Son, 2005; Sternberg & French, 1993). This requires teachers to provide multiple examples of the concept in a wide range of contexts so that learners can identify relevant similarities and differences between the contexts. This practice addresses the strategic aspect of the coordination class, with the question of where the concept is and is not useful, as learners seek out the common aspects of contexts where a particular concept can be applied. The alternative is to spend more time on an in-depth investigation of the concept in one context, as in project-based learning.

In the states of matter example, this would look like:

In-depth: Where are solids, liquids and gases involved in the change from ice to water to steam? How do you recognise them? Where might you find examples of these?

Generalisation: Where are solids, liquids and gases in these examples? How do you recognise them? How are they the same? Different?

To investigate the impact of these three factors in the classroom, they needed to be incorporated into a classroom learning program that is part of the regular curriculum. The challenge was to develop classroom learning programs that not only incorporated the pedagogical factors in control and experimental forms but controlled for a range of other variables such as time on task, mode of presentation, and information presented. The classroom teaching and learning program is included in Appendix M. This section reports the test drive of this program with three classes of students in a school setting. After the pilot study, the materials were refined for used a larger field study.

5.2.2 Method

5.2.2.1 Participants

Participants were 86 Year 5 students (age 10-11 years) in three classes in a large suburban South Australian primary school, and their science teacher, selected as the teacher had offered to be part of the research. The classes were taught science in a weekly 100 min session by the same teacher. This trial ran for an initial four weeks and was then followed up with two separate tasks, one after a further four weeks and a second 10 weeks after the last task. Ethics permission was sought and received from Flinders University Social and Behavioural Research Ethics Committee and the Department of Education and Child Development (see Appendix N).

5.2.2.2 Materials

A set of teaching and learning materials was developed that addressed the mandated curriculum entitlement of the Australian Curriculum: Science (ACARA, 2021a) for these students outlined in Table 5-1.

Table 5-1 Australian Curriculum: Science Chemical Sciences year 5

Curriculum component	Description
Year level description	They broaden their classification of matter to include gases and begin to see how matter structures the world around them.
Content description Science Understanding Strand Chemical sciences sub strand	Solids, liquids and gases have different observable properties and behave in different ways
Achievement standard	Students classify substances according to their observable properties and behaviours

The 5E's teaching model (Bybee, 2015) was used since that is consistent with Teaching for Effective Learning (TfEL), which is the mandated pedagogical framework for this school (Department of Education and Children's Services, 2010), and used by the Primary Connections program[13], which is also endorsed by the Department of Education and child development. The learning program consisted of a sequence of 12 tasks as described in Table 5-2.

[13] https://primaryconnections.org.au/

Table 5-2 Sequence of tasks in the Solids, liquids and Gases learning materials

5E's Learning model phase	Task	Detail
1 Engage (prior knowledge)	1a Fire extinguishers prior knowledge	Watch a video demonstration of 5 different fire extinguishers. Answer: *What might happen to the different materials after the fire has gone out? How are solids, liquids and gases involved?*
	1b Framing video explainer	Watch a video about classifying materials. Answer: *What might you be learning about? Why is it useful? What do you already know about it?*
2 Explore	2 Classification task	Classify 10 samples of materials, explaining how the groups differ.
3 Explain	3a Solids liquids and gases classification video explainer	Watch a video about the key properties and behaviour of solids, liquids and gases. Respond to prompts to reproduce the main ideas.
	3b The important stuff summary sheet	Summarise your understanding of the important features of solids, liquids and gases
4 Elaborate	4a In action	Identify and explain solids, liquids and gases in an image of jet trails and the properties of a mystery liquid
	4b Particle drama	Participate in a drama model of the behaviour of particles in solids, liquids and gases
	4c Volcanoes	Identify and explain solids, liquids and gases in images of volcanoes erupting
	4d Honeycomb	Identify and explain solids, liquids and gases in observation of making honeycomb (toffee)
	4e Water	Identify and explain solids, liquids and gases in different naturally occurring forms of water
5 Evaluate (end of unit)	5a Fire extinguishers summative assessment	Repeat Tasks 1a and 1b from the beginning of the sequence
Evaluate (4 weeks after end of unit)	5b The coyote cartoon storyboard	Identify the most important idea about solids, liquids and gases and use it to write a storyboard for a new episode of a cartoon
Evaluate (10 weeks after end of unit and away from science setting)	5c Camp cooking	Consider implications for storage and handling of different cooking fuels

Teaching materials are available in Appendix M.

The teaching materials included a set of slides scaffolding the lessons steps for the teacher, videos of the learning content, printed student record sheets and class sets of all equipment and materials for practical tasks. All activities involved a written response, scaffolded by a reproduced sheet. Although a frequent comment from students at the end of unit feedback was that there should be fewer written responses, work samples showed consistently good engagement throughout the unit. Students were positioned by the teacher as test drivers for the materials and informed that their thinking would be valued. The school assessment for the topic was done in additional tasks.

5.2.2.3 Experimental design

The study used a quasi-experimental design as students were nested in classes, which meant that the independent variable (pedagogy) could be randomised across the classes but not students. The dependent variable (transfer) was measured from the work samples produced by students in response to each task. The school, teaching space and teacher were kept constant, and the learning program was constructed using identical materials, images, slides and record sheets, except for variations to cater for different pedagogies. Video length and time on task were kept as similar as possible across the three sets of materials.

The opportunity for the research to be carried out in three classes, all taught by the same teachers, was valuable since it removed variability associated with the teacher. In addition, the classes were not streamed, minimising variation between them. However, limiting the pilot study to three classes did not allow investigation of each of the three factors independently, and in combination, so a decision had to be made about distributing the variables amongst the classes. The experimental design is set out in Table 5-3.

Table 5-3 Distribution of variables for each of the 3 classes

Variable	Class A	Class B	Class C
Framing	Bounded	Expansive	Expansive
Challenge	Tell and practice	Tell and practice	Productive struggle
Contexts	In-depth study of a few contexts	Generalisation from multiple contexts	Generalisation from multiple contexts

The program for Class A is well represented in existing practice in many primary science classrooms in South Australia. Many teachers of science, even primary science specialists, are teaching outside their field of expertise, and the framing of the learning in terms of other science and its role in the community is not something they are confident with. This lack of science content knowledge is combined with a dominant pedagogy of relationships and rescue, characterised by supporting and scaffolding students for success at all stages (Foster, 2020). A pedagogy of direct instruction with support is not unique to South Australia. Zvoch, Holveck and Porter (2021) reported that this has been common in U.S.A. science classes for decades.

The program for Class B involved two of the three experimental variables, expansive framing and generalisation, but kept tell and practice pedagogy. Here extra framing information and tasks with other contexts were added, requiring the lessons to move faster, but tell and practice pedagogy was kept to support and scaffold students as much as needed. This pedagogy would be characteristic of an informed and well-meaning teacher with good science content knowledge and a desire to see students succeed.

Finally, with all three experimental variables, Class C received the extra information and activities but delivered with productive struggle pedagogy. Delivering this pedagogy, especially without the support of detailed a learning program or pedagogy coach, requires good science content knowledge and confidence in students' capacity to engage with tasks where they have to generate and refine their own solutions paths. It is less commonly adopted in South Australian primary schools (Foster, 2020).

The Pedagogy of Classes A (no experimental factors) and C (all three experimental factors) were obvious choices for combinations of the three factors. For the remaining class, there were three possible combinations with only one only experimental factor and three with exactly two experimental factors. While each of these corresponds to a recognisable classroom profile, that eventually chosen for class B is probably one of the more common. The experimental design allows for the attribution of any variation in transfer in Class C compared to the other classes to the productive struggle rather than the framing or number of contexts.

The teaching and learning sequence described above was varied as follows:

5.2.2.3.1 Framing (see video scripts in Appendix M)

Bounded – engage video framed as learning about solids, liquids and gases as this term's topic.

Expansive – engage video framed as learning about classifying materials to understand the world and as a foundation for future learning.

5.2.2.3.2 Productive struggle (see video scripts in Appendix M)

Tell and practice – order of Tasks 1a,3a,2a,3b … so that students were given an explanation about solids, liquids and gases before a practical application of classifying samples of materials. Video scripts also provided information before prompting for a response.

Productive struggle – order of Tasks 1a,2a,3a,3b … so that students observed and attempted to classify samples of materials before the explanation about solids, liquids and gases. Video scripts prompted for response before providing information. Both strategic and functional aspects of the concept were presented using productive struggle.

5.2.2.3.3 Generalisation from contexts

In-depth – the class did not complete 4c and 4e from the elaborate phase but spent more time on the other three activities.

Generalisation from multiple contexts – class completed all five activities in the elaborate phase.

5.2.2.4 Procedure.

The unit was taught in the first five weeks of the third term of a four-term school year by a specialist science teacher in a science teaching space separate from the students' regular classrooms. After Task 5a, the class moved on to another topic for the rest of the term. Task 5b was completed in the last week (week 10) of the term in the science teaching space, while Task 5c was completed ten weeks later. Task 5c was given by the students' classroom teachers in their regular classrooms and thus represented far transfer in the physical and temporal dimensions (time and place) of Barnett and Ceci (2002).

In addition to providing materials, the researcher met regularly with the classroom teacher to clarify any issues or reinforce the difference between the three pedagogies.

5.2.2.5 Measures

As with the qualitative studies described in Chapter 4, this pilot study was carried out before the frameworks outlined in Chapter 3 were finalised, and so while the measures use similar language, they are not in the final format. This study used qualitative and quantitative methods to examine student work samples for evidence of transfer. Qualitative study of the work samples identified the range of evidence of transfer, and this was used to select and adapt frameworks describing various aspects. Following this, quantitative data was collected on the frequency these aspects of transfer occurred in the three classes. These results are presented as descriptive statistics.

5.2.2.5.1 Framing

In an open-ended response question, students were asked twice (once at the beginning in Task 1b and once at the end in Task 5a) why they thought the learning might be important. Their responses were initially grouped under these headings:

A. Understanding the world
B. Future education
C. Job or work
D. Teaching others

E. General reference to future

F. Grades

The first five were interpreted as evidence of expansive framing, the sixth of bounded framing.

5.2.2.5.2 Transfer of the targeted science concept

Student responses were scored according to two-cycle SOLO framework (Biggs & Collis, 1982; Panizzon et al., 2006). This scoring involved an initial classification into three groups based on the reference to states of matter or their properties. Pre-structural responses showed no evidence of this, first-cycle responses showed evidence in everyday language such as *gases go wherever they want,* or *gases disappear into the air, while* second cycle responses made referred to key distinguishing properties or behaviours of gases such as shape, size, flow and tendency to fill a container. The levels were distinguished within the first and second cycles, as shown in Table 5-4.

Table 5-4 Coding of student responses based on SOLO

Level	Code	Description
Pre-structural	P	no relevant reference to solids, liquids and gases or their key properties
Uni-structural (first cycle)	U1	identifies an example of solid, liquid or gas or generic everyday reference to key property
Multi-structural (first cycle)	M1	identifies a key property in everyday language
Relational (first cycle)	R1	uses a property to explain a phenomenon
Uni-structural (second cycle)	U2	generic reference to shape or size
Multi-structural (second cycle)	M2	identifies key properties of shape and size or behaviour of flow
Relational (second cycle)	R2	uses key properties of shape and size or behaviour of flow to explain a phenomenon

5.2.2.5.3 Strategic aspects of the concept

Only the fire extinguisher task (Tasks 1a and 5a) and the camp cooking fuels (Task 5c) offered affordances for students to demonstrate transfer of the strategic aspects of the concept as all other tasks either cued the concept by including solids, liquids and gases in the prompt, or were sandwiched between other tasks which cued the concept so students would have already been primed for it. In an attempt to distinguish strategic (uncued transfer) from functional transfer where the concept was cued, students were given some time to respond before being prompted to use the intended learning of solids, liquids and gases in their response. To identify uncued and cued transfer on the written response sheet, they were asked to underline the existing references to solids, liquids and gases before continuing with the cued response. This strategy proved to be unreliable in that absence of underlining could reflect no spontaneous transfer or no engagement with underlining, and full underlining could reflect all spontaneous transfer or underlining of everything relevant. The only available indication of spontaneous transfer was those ideas nearer to the beginning of the response.

5.2.2.5.4 Feedback

After Task 5a, the summative assessment task, students completed a questionnaire that asked:

1. what they had learnt;
2. why it might be important to them;
3. what helped them learn this;
4. any other feedback about the unit.

Question 2 contributed to the framing described above, and the other three questions were analysed separately.

5.2.3 Results and discussion

5.2.3.1 Framing

Students' responses to the two questions about why the learning might be important are shown in Table 5-5, **Error! Reference source not found.** and **Error! Reference source not found.**. Class B did not complete the second review sheet, so their responses from the end of the unit are missing.

Table 5-5 Student response to the question of why learning might be important.

(Percentage of all students present - percentages may not add up to 100% as some students gave no feedback and some gave feedback that aligned to several categories)

Class	A		B		C	
Before or after learning	Before (n=30)	After (n=29)	Before (n=26)	After	Before (n=22)	After (n=27)
Understanding the world (W)	63%	59%	77%		82%	58%
Future education (E)	20%	14%	8%		0%	7%
Job, work (J)	10%	14%	4%		0%	26%
Teaching others (T)	0%	7%	0%	Task not completed	0%	0%
General references to the future (F)	3%	10%	0%		5%	0%
Grades (G)	3%	3%	0%		0%	4%
General reference to science (S)	0%	7%	0%		9%	0%

Figure 5-1 Initial student framing of the intended learning

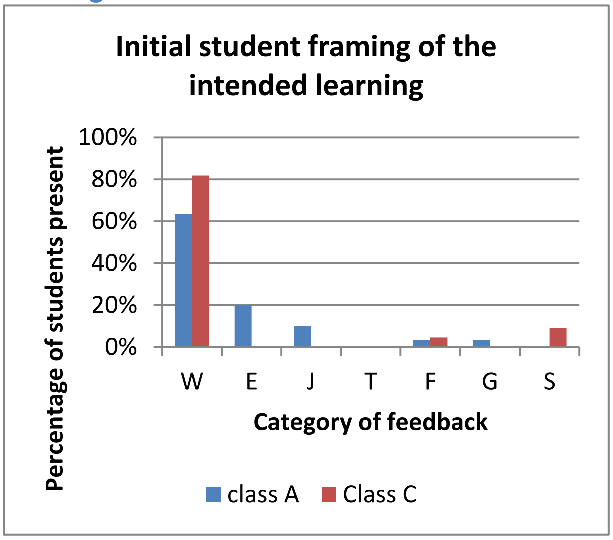
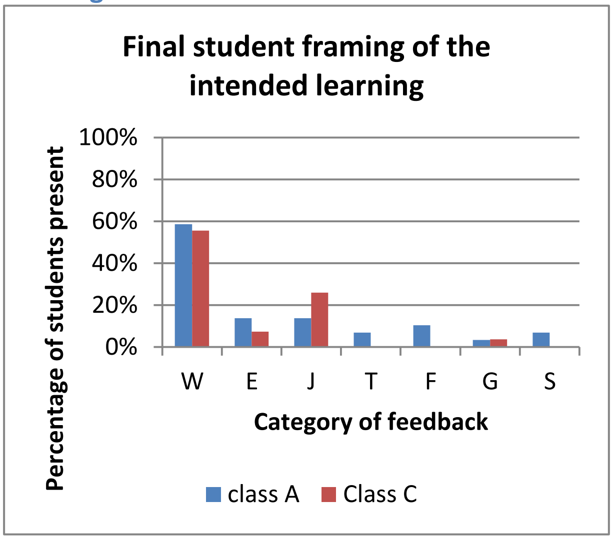


Figure 5-2 Final student framing of the intended learning



At both the beginning and end of the teaching sequence, students overwhelmingly cited understanding their world as the main purpose of learning about states of matter. Responses varied from the profound (*make sense of the universe, understand the world and live a better life)* to the less profound (*so I know what I'm eating*). Safety was a common theme. Some reflect the school's participation in the International Baccalaureate Middle Years Program, in which understanding the world is a recurring theme. The majority of responses were consistent with mastery goals (see Kaplan, Gheen and Midgley (2002) for a review of goal structure) and expansive framing, with only one response at the beginning citing getting good grades, which is more consistent with performance goals and bounded framing. This was encouraging in terms of students' disposition to engage meaningfully with the learning experiences. More students cited factors other than understanding the world after the unit, although these were still in the minority.

5.2.3.2 *Transfer of the targeted science concept*

Although the average transfer of the science concept (targeted transfer), as shown by evidence of SOLO second cycle thinking (codes U2, M2 and R2) across all tasks, was 15%, there was considerable variation between classes, as is shown in Table 5-6.

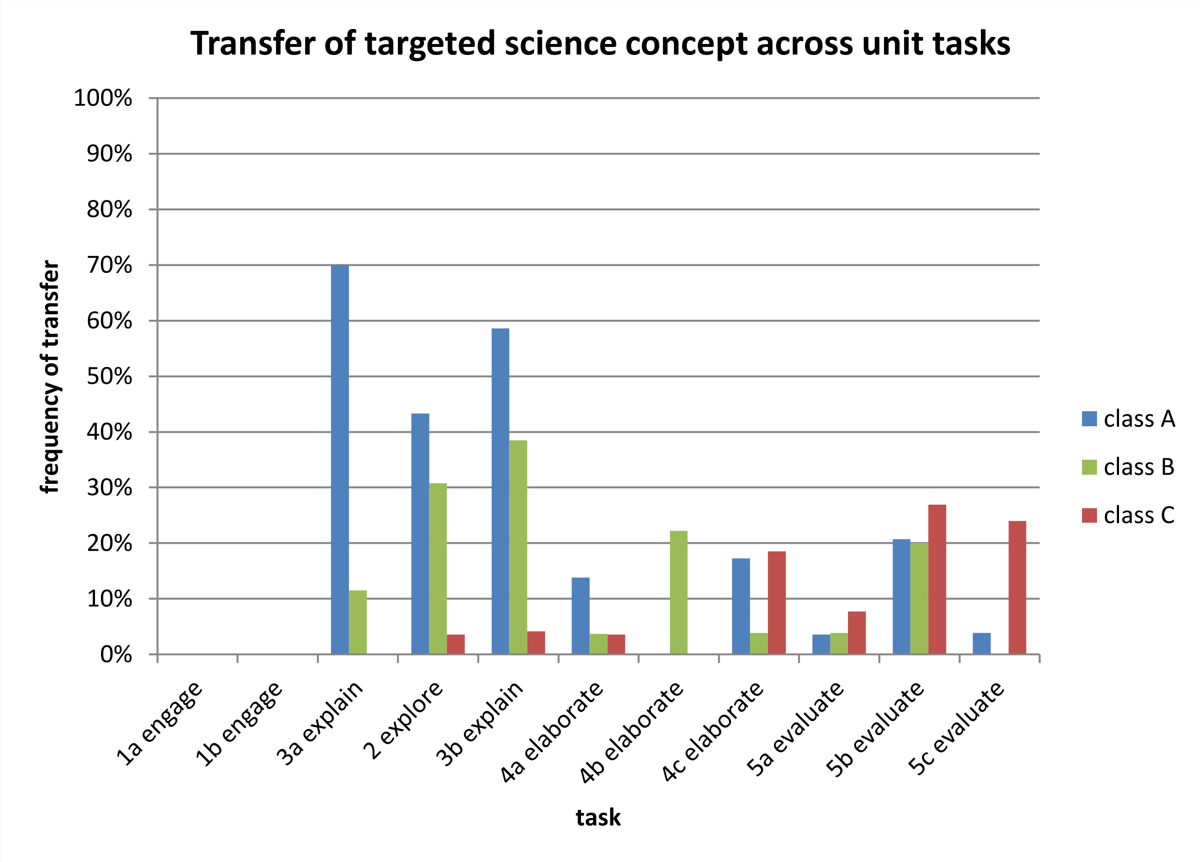
Table 5-6 Comparison of the percentage of students transferring the targeted science concept in the evaluation tasks

Class	Transfer of targeted science concept			
	Evaluate 5 a	Evaluate 5b	Evaluate 5c	All unit tasks
A	4%	21%	4%	23%
B	4%	20%	0%	14%
C	8%	27%	24%	9%
Odds ratio C/A	2.2	1.3	6.2	.34

A one-way analysis of variance (ANOVA) indicated that the difference between Class B and Class C in the proportion of students transferring the targeted concept in Task 5c, was statistically significant ($p<0.05$). The effect size (eta squared) is 0.125, which is a medium to large effect (van den Berg, 2020). Because of a significant Levene's test, homogeneity of variances could not be assumed so a Games-Howell test was used. The ANOVA is included in Appendix O.

As the only difference in pedagogy between these two classes was the use of productive struggle in Class C compared to the tell and practice in Class B, the increase in transfer can be attributed to the productive struggle pedagogy. With their simplified content and tell and practice pedagogy, class A produced well over twice the overall amount of targeted transfer (23%) compared to class C (9%) with productive struggle and expansive framing. Class B fell between the two. However, this was not uniformly distributed across the sequence of tasks in the unit, as shown in **Error! Reference source ot found.**.

Figure 5-3 Percentage of students transferring the targeted concept for each task



There was considerable variation between tasks as well as between the three classes. For the classes with tell and practice pedagogy, targeted transfer was generally highest in the two explain tasks, unsurprisingly because this involved reproducing material that had just been presented to them on video. The exception was Class C with the productive struggle methodology, where the explain video asked them for their ideas before the explanation was presented. Although students could revise their recording after the explanation, few took up this opportunity. Targeted transfer was also high in the explore task where students applied the classification they had just been given to a set of material samples. Again, this was done before the explain task with Class C, so transfer was low.

The high proportion of targeted transfer in Class A in the early explore and explain phases of the learning sequence attenuated after the initial task of the elaborate phase and did not reach near this level again. There was no evidence of the targeted science concept by the final far transfer task (task 5c). Evidence of targeted transfer by class B was strongest in the explain phase immediately after the explainer video and then fell below the other two classes for the rest of the sequence of tasks. Comparing classes A and B, it seems that expansive framing and multiple contexts did not result in more students showing targeted transfer with tell and practice pedagogy.

On the other hand, class C, which also experienced expansive framing and multiple contexts, showed a different trajectory through the learning sequence. Responses from these students showed the least targeted transfer of all three classes early in the learning sequence, probably due to the confusion they were trying to work through. However, their targeted transfer was the highest of all classes at the end of the teaching and especially beyond. Even though across all tasks, they showed less than half the incidences of transfer of the causal net shown by class A, class C produced targeted transfer where it mattered - the far transfer of the evaluation tasks. Here, they were six times more likely to show transfer in the final far transfer task. It appears that for those who survive the initial productive struggle, there are later dividends in being set up to transfer this later on.

As a side issue, this raises the question about how well the practice of continuous assessment (assessing students regularly throughout their learning rather than a final test) measures students' capacity to transfer in the long term. None of the students of Class A who showed several incidences of targeted transfer over the course of the unit demonstrated this in the far transfer task. By contrast, four of the six students in Class C who did transfer in the far transfer task had only provided evidence of transfer once before.

5.2.3.3 Strategic aspects of the concept

Since the tactic of underlining to responses produced before the cue was not reliable, the only way to gauge what learners transferred unprompted was to look at the order of ideas in their responses. The majority of the earlier parts of responses showed minimal readout of gases (the intended learning) and no causal net related to them. Therefore there was little evidence that learners transferred the strategic aspects of the targeted concept, and so evidence of targeted transfer in this unit is limited to evidence of a causal net about gases. Task design would need to be modified in future studies to provide more information about transfer of strategic aspects of the concept.

5.2.3.4 Transfer of learning other than intended learning – everyday causal nets

In interpreting student work samples for this investigation, there was considered to be evidence of the targeted science concept if students used scientific terminology such as shape, size, volume, flow to explain the link between state of matter and properties or behaviour. However, in every class, a proportion of responses used everyday language to describe thinking related to the targeted science concept but not precise enough to be considered evidence of it. For example, a student who claims that gases disappear may mean that they disperse at such low densities as to make them invisible or that the gas ceases to exist. Similarly, a student who claims that gases float has not made the dispersion part of their behaviour clear. Other students may misinterpret terminology. Two students interpreted the "volume" referred to in the video description of the distinguishing properties of solids, liquids and gases as a property of sound and made several references in other tasks to the different sounds of the three states of matter.

These everyday causal nets can be surprisingly persistent, as shown in the following two responses from the same student.

Immediately after the video explainer that involved a demonstration of the fine solid particles in smoke:

“I thought smoke was a gas, but turns out it’s a solid”

Four tasks later from the same student in response to an image of jet trails:

“Smoke is a gas and always will be”

Although this student’s notion of the state of matter has been challenged, they shortly reverted to their previously held beliefs. Likewise, a different student responding to the video explainer showing particles of soot from candle smoke collecting on a white plate:

“Smoke is a gas until it touches something and then it turns into a solid”

This student has invented a causal net to explain the observation and still protect his basic belief about smoke being a gas. Both students had missed the point from the video that smoke is a mixture of different substances in different states of matter.

Table 5-7 shows the frequency of students using everyday causal nets across all tasks.

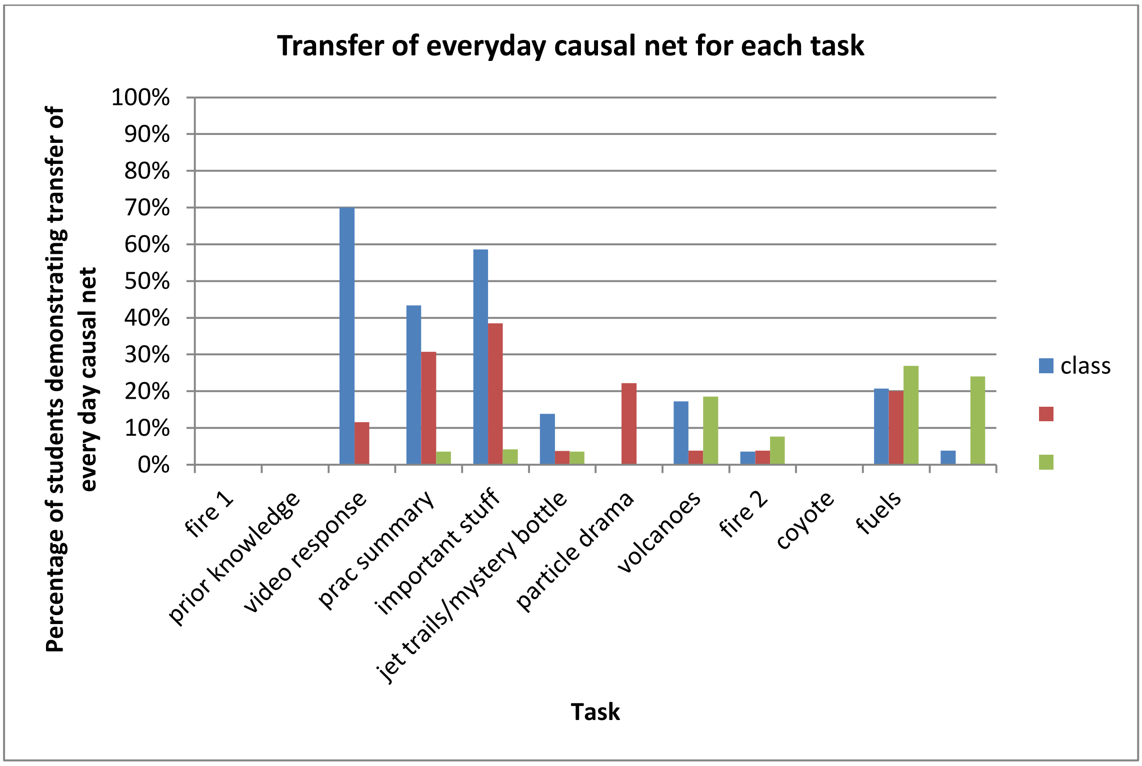
Table 5-7 Proportion of students using everyday causal nets across all tasks

Class	Average everyday causal net for intended learning for each task
A	52%
B	66%
C	61%

As well as showing the most transfer of the targeted science concept, Class A also showed relatively frequent transfer of the everyday causal net. Class B also showed frequent transfer of the everyday causal net, while Class C transferred at about half the rate.

The distribution of these responses for each class across the 13 tasks is shown in **Error! Reference ource not found.**.

Figure 5-4 Everyday causal net across all tasks



For Class A, transfer of an everyday causal net was lowest in the explain tasks, where students were reproducing a science concept that had just been presented. After this, it tended to rise, becoming the highest of all classes in the evaluate phase as students did not invoke the science concept they had reproduced before. For Class B, the everyday causal net was relatively high all the way through as they struggled to take on board all the information presented to them. For at least some students in Class C, it seemed that productive struggle has lived up to its name, as over 90% transferred only an everyday causal net while they struggled with the science version. This transfer of an everyday causal net decreased over the rest of the unit as they gradually took on the science version.

5.2.3.5 Transfer of learning other than intended learning – other causal nets

The properties and behaviour of gases were not the only causal nets triggered by the contexts. Safety and potential danger, particularly in relation to flammability and toxicity of gases, featured in 62% of responses alongside those related to the intended learning. These students have a foot in both camps – they are unsure how useful the new causal net relevant to gases is in these contexts and unwilling to let go of the tried and proven concepts, particularly those related to flammability and toxicity.

5.2.3.6 *Trajectories of students through the learning sequence*

The analysis so far charts the trajectory of the three classes through the learning sequence. This section looks at the trajectory of individual students within these groups, focusing on the causal net of the intended learning. The trajectories presented in Table 5-8 columns 2 to 5 have been grouped according to the transfer shown in the evaluation tasks. Trajectories E and F demonstrated transfer in at least one of the evaluation tasks; the E trajectories in the far transfer Task 5d and the F trajectories in at least one of the other two, Tasks 5a and 5c. There was no evidence of transfer in the evaluation task for the G trajectories, despite some in the preceding tasks, and finally, the H trajectory showed no evidence of transfer in any of the tasks in the unit. The percentages of students in each of the three classes demonstrating these trajectories are shown in Table 5-8.

Table 5-8 Trajectories of learners through the learning sequence.

(Increasing intensity of blue shading reflects increasing frequency of targeted transfer.}

	Prior knowledge	Explain	Elaborate	Evaluate (3 tasks)	Number of students (%)			
					Class A	Class B	Class C	All students
E1	none	At least 1 task	none	Far transfer (Task 5c)	1 (3%)	0	0	1(1%)
E2	none	none	At least 1 task	Far transfer Task (5c)	0	0	3 (11%)	3 (3%)
E3	none	none	none	Far transfer Task (5c)	0	0	3 (11%)	3 (3%)
F1	none	At least 1 task	At least 1 task	At least 1	3 (10%)	2 (7%)	1 (4%)	6 (7%)
F2	none	At least 1 task	none	At least 1	1 (3%)	1 (4%)	0	2(2%)
F3	none	none	At least 1	At least 1	0	2 (7%)	0	2(2%)
F4	none	none	none	At least 1	2 (7%)	1 (4%)	4 (14%)	7(8%)
G 1	none	At least 1 task	At least 1 task	none	5 (17%)	1 (4%)	0	6(7%)
F2	none	At least 1	none	none	12 (40%)	7 (25%)	0	19 (22%)
G 3	none	none	At least 1	none	0	2 (7%)	1 (14%)	3(3%)
H	none	none	none	none	6 (20%)	12 (34%)	16 (57%)	34 (40%)

The first group of trajectories, E1-E3, culminated with evidence of far transfer, but interestingly with little or no transfer before. The majority (6/7) of these students came from the productive struggle class (Class C), and none came from class B. The next group of trajectories, B1-B4, all had evidence of transfer in either 5a or 5b or both. Many of those from classes A and B also demonstrated transfer in at least some preceding tasks, while a group from all classes, but particularly class C, showed no evidence of previous transfer. Trajectories, G1-G3, occurred mostly in Classes A and B and showed no evidence of targeted transfer in the evaluate tasks despite some evidence in the tasks before. Finally, the largest group, H, showed no evidence of transfer of the targeted science concept in any task. All three classes were well represented in this group, but it accounted for over half of Class C.

Thus, there were multiple paths to both successful and unsuccessful transfer of the intended learning amongst these learners. Even those learners in the same class with the same pedagogy took between 6 and 8 different trajectories through the learning sequence. There were some similarities in the trajectories of learners in classes A and B, in that they demonstrated early initial transfer, which disappeared, while those in class C showed the reverse. Of the eleven trajectories, four were found only in one class, and the remaining eight occurred in at least two classes.

For teachers of primary school students, it will be no surprise that different students can participate in the same sequence of learning activities and arrive at very different outcomes. What works for some does not necessarily work for others. Faced with 30 learners and limited time, teachers need to choose pedagogy that will benefit the maximum number of learners and respond to those who are not experiencing success. The caution from this study is that early success does not necessarily translate into long term success.

5.2.3.7 Student feedback on the learning experience

Students' responses to the feedback questions were scored for the idea(s) provided, and then these ideas were grouped into categories. The responses of classes A and C are compared here as Class B did not complete this task. Fifty-four students were present for the task

5.2.3.7.1 What did you learn?

Across the two classes, 20 different ideas were put forward in response to this question. Most of these ideas fell into one of two groups - general ideas such as properties, behaviours and how to distinguish them or context-specific ideas such as *smoke is a solid*, *how to make honeycomb* or *which substances put out a fire*. Two students offered ways to sort or vocabulary, which did not fit into either. Table 5-9 shows the distribution of these responses across the two classes.

Table 5-9 Percentage of student feedback about what they learnt

Type of feedback about what students learnt	Class A	Class C
Generic	90%	55%
Context specific	10%	38%
Other	0%	8%

In the summative assessment tasks completed at the same time as and after this feedback was given, more of Class C demonstrated targeted transfer than Class A (39% vs 23%), yet when asked to describe what they had learnt, more Class C students tied their responses to particular contexts. This could reflect the concrete and specific nature of these students' learning or their inability to articulate a generalisation in this context.

5.2.3.7.2 What helped you learn?

Together students nominated 24 ideas about things which had helped them learn, including behaviour, e.g. memorising, concentrating, talking; activities, e.g. drama, experiments; and resources, e.g. videos, the teacher, worksheets. Eighteen of these appeared only once, and the distribution of the others is shown in Table 5-10.

Table 5-10 Percentage of students who nominated these aspects of the learning as helping them learn

Response to What helped you learn?	Class A	Class C
Videos	90%	64%
Table test (part of the video)	10%	4%
Material samples activity	21%	16%
Drama activity	3%	16%
Worksheets	3%	20%
Honeycomb	0%	20%

Students in Class C nominated a wider range of things that helped them learn than those in class A. In particular, the explain video for class A with its explicit explanation (including the table test) seems to have been the main driver for learning in the opinion of Class A students. By contrast, the explain video for class C with its built-in productive struggle did not rate as high, and their nominations covered a range of other activities.

5.2.3.7.3 Any other feedback?

The diverse range of offerings in response to this prompt was grouped under four headings:

- emotional responses, e.g. I liked it, it was fun, honeycomb was tasty;
- responses targeting activities, e.g. more experiments, can we go outside, less worksheets;
- responses related to cognition, e.g. I learnt …, it was challenging, I already knew this.

The distribution of these groups of responses is shown in Table 5-11.

Table 5-11 Percentage of other feedback in each category

Content of other feedback	Class A	Class C
Emotional	29%	58%
Activities	45%	22%
Cognition	17%	14%
Other	7%	6%

Most feedback involved either an emotional response or a comment about learning activities, and there were clear differences between the classes. Class A focused more on the activities and Class C on the emotional response.

The association between student feedback and the level of targeted transfer of the targeted science concept demonstrated in the far transfer Tasks (5a, 5b and 5c) seems almost counterintuitive. How can it be that Class C, where students described their learning in terms of context-specific and almost irrelevant details rather than generalities, and where feedback focused on emotional aspects rather than learning activities, demonstrate more transfer of the causal net than Class A. While this study is too small in terms of the number of students and the data collected to investigate this question further, it suggests that student feedback may provide insights into factors related to the students themselves beyond that gleaned from work samples. This avenue was explored further in the larger field trial.

5.2.3.8 Impact of the strategies on transfer of learning

Because of the limited number of classes available, expansive framing and generalisation from multiple contexts were treated together. In the absence of productive struggle, there is little evidence that they improved targeted transfer at any stage in the learning sequence. However, when combined with productive struggle, targeted transfer in the short term was compromised but enhanced in the long term. Further evidence needs to be obtained to address whether productive struggle alone is sufficient to improve targeted transfer. In addition, there is evidence from this experiment that without productive struggle, expansive framing and generalisation from multiple contexts are damaging to targeted transfer.

5.2.3.9 Effectiveness of the teaching and learning task sequence

Overall, transfer of the targeted science concept was highest (35%) in response to the explainer, which is about as near to the learning experience as possible. Far transfer came in at a maximum of 23% for the coyote task and less for the rest of the tasks. Thus the proportion that did not develop their ability to transfer from their experience with these learning materials is quite high. The learning program failed to promote targeted transfer in more cases than it succeeded. Some strategies to address this include:

- Changing the productive struggle procedure from simply reversing the tell and practice, to a three-stage procedure in which students seek an answer, are provided with access to one and then practice using this. This third practice stage would allow students to consolidate the intended learning.
- Providing more specific access to the language, particularly vocabulary, necessary to think about and communicate the science concept with sufficient precision and clarity. This might help the many students who continued to use everyday causal nets even after being provided with the scientific version.
- Providing feedback for students on their responses before the next task. During analysis of the responses, it was noticed that misuse of language or over-generalisation that appeared in one task response often persisted throughout the remainder of the task sequence. The learners who interpreted the "volume" in the video description of the distinguishing properties of solids, liquids and gases as a sound property persisted with this through several other tasks. Feedback was limited to oral class discussion and required students to volunteer their ideas and actively reconstruct them in the light of feedback, and many students would have had no feedback at all on their ideas. A self and peer assessment strategy needed to be developed to make this manageable.

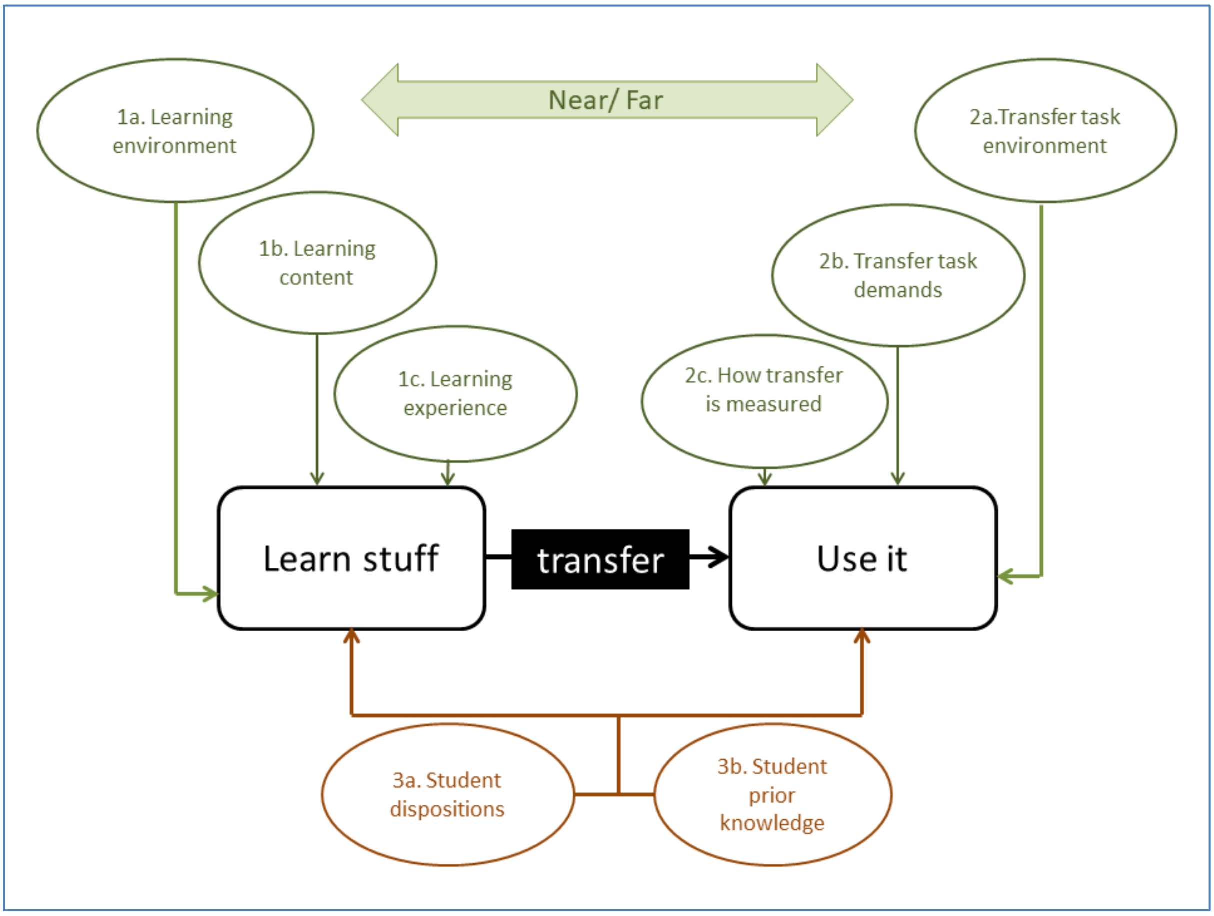
These modifications were part of the field study in the next section.

5.3 Classroom strategies to support transfer – a field trial

5.3.1 Introduction

The literature review in Chapter 2 yielded a number of factors, for which there is evidence of their impact on transfer of learning. These were grouped into those related to the initial learning experience, the transfer experience and the students themselves, as shown in **Error! Reference ource not found.** (repeated from **Error! Reference source not found.** as an organiser for the following discussion of these factors).

Figure 5-5 Factors affecting transfer of learning



The qualitative studies described in Chapter 4 and Chapter 5-1 provided evidence for the impact of a number of these:

- The original learning

- *The learning experience*. Findings from the pilot study in Chapter-1 suggested that the combination of expansive framing, productive struggle and examples from multiple contexts may yield less near transfer but more far transfer;
    - *The learning content*. Transfer decreased with more abstract concepts (Chapter 4-1 and 4-2);
- The transfer situation
    - *The demands of the transfer task*. Cuing the targeted concept and requiring reproduction rather than application of the causal net result in more transfer (Chapter 4-2 and 4-3 and Chapter 5-1). Requiring explanations of connections between ideas decreased transfer compared with descriptions of single ideas or phenomena (Chapter 4-3);
    - *The difference between the original learning experience and the transfer task*. Near transfer is easier to achieve (Chapter 5-1);
- The students themselves
    - *The age and associated developmental stage*. Older students did not always demonstrate transfer of the higher level of conceptual thinking described in the curriculum, and many remained at level 1 (Chapter 4-3).

Because of the small number of participants, it is not possible to generalise the findings beyond the research circumstances. In addition, factors relating to the learning environment, learning experience, student dispositions and prior knowledge were not addressed. A larger field study of transfer was carried out to address some of these gaps.

Studies of the impact of a range of factors on transfer of learning are more common in the field of professional learning or workplace training than in school-based learning, and factors relating to the culture of the workplace itself feature prominently (e.g., Kohn (2016); Leberman et al. (2016);(McCullum, 2017)). Research into transfer of learning in schools is more likely to investigate the impact of a single factor (Abercrombie (2013); Kruit et al. (2018); Schwartz et al. (2011)). Peters et al. (2015) combined a range of factors thought to improve transfer of learning into a single health program, and in a study involving 1107 students, found it to be effective in fostering transfer of learning. Zvoch et al. (2021), investigating the effect of a single factor, student-centred versus teacher-directed pedagogy, found no significant difference until student prior achievement was taken into account. Given the failure to identify the effect of single factors (see, for example

(Detterman, 1993)), it seems that multiple interacting factors affect what learning students transfer in any situation.

The study reported in this section aimed to investigate the impact on transfer of science concepts of a range of factors, especially those not addressed in Chapters 4 and 5-1. These include factors relating to pedagogy, tasks and in particular the learners themselves. Deakin Crick and Goldspink (2014) highlighted the potential for learner dispositions to influence engagement and achievement and measures of these were included here as described in the method section 5.3.2.2.4, thus providing data on factors relating to the learners themselves. In addition, this study involved a larger sample size and incorporated the modifications from the study in Chapter 5-1. Qualitative and quantitative methodology was used to investigate evidence of transfer of science concepts by Year 6 students.

5.3.2 Method

5.3.2.1 Participants

Participants were 244 Year 6 students (aged 11-12 years) and their teachers from 4 large metropolitan primary schools in South Australia, as described in Table 5-12.

Table 5-12 Summary of participating schools, classes and students.

School	ICSEA	Attendance[15]	LBOTE[16]	Class	Teacher	Participants

[14] Index of Cultural, Social and Educational Advantage. Data from Myschool website https://www.myschool.edu.au/
[15] Attendance data from Myschool website
[16] Language Background Other Than English data from Myschool website

		Average	Students attending over 90%				
A	1155	95%	88%	55%	1	T1	16
					2	T1	22
					3	T1	21
					4	T1	21
B	1134	94%	82%	39%	5	T2	30
					6	T2	25
C	1090	94%	81%	68%	7	T3	7
					8	T3	13
					9	T3	19
D	1144	95%	87%	29%	10	T4	26
					11	T5	25
					12	T6	19
averages	1130	95%	85%	48%	Total 12 classes	Total 6 teachers	Total 244

5.3.2.1.1 Teachers

The teachers had responded to a flier calling for expressions of interest in the project. All four of the responding teachers were specialist science teachers, with multiple (4, 2, 3 and 3) classes at the same year level, although one specialist teacher (school D) passed participation in the project to the 3 class teachers. One teacher was experienced in teaching and science, two were relatively new graduates, and two had more classroom teaching experience. Throughout the project, there were the usual school changes in teaching personnel. Two moved to leadership positions, and the replacement teachers continued the school's participation in the project, while others had varying amounts of days away from their classes, with the lessons being taken by relieving teachers. Teachers reported that they had explained the teaching procedure to the replacement teachers.

Teachers spent varying amounts of time with their classes each week. One school with about 2 hours a week devoted to science finished the two units comfortably in two terms, while other teachers saw students for as little as 50 minutes a week and required over three terms to complete the two units. Two teachers had specialised science teaching space, while the remainder taught in students' everyday classrooms.

5.3.2.1.2 Schools

The four metropolitan primary schools involved in the research shared common demographic features. All ranked more than one standard deviation above the median on the Index of Educational and Social Advantage (ICSEA)[17] (average 1133, national median 1000 and a standard deviation of 100). Their attendance rates were relatively high, and a relatively high proportion of students came from a language background other than English. The differences between the schools are shown in Table 5-12.

5.3.2.1.3 Students

Although all students in the classes of the participating teachers took part in the learning program, assessment activities and surveys, the data used in the research was from the 69% of students whose parents had returned a consent form. Participation rates for the four schools ranged from 51% to 87%. The sample size for analysis was affected by students missing learning activities because they were absent from school or in-school reasons like music lessons, individual support and sport.

5.3.2.2 Research materials

5.3.2.2.1 Learning materials

The learning involved two units of work consistent with the mandated curriculum for Year 6. The Unit 1 topic was earthquakes, targeting the concept of interacting tectonic plates to explain and predict earthquakes. Unit 2 was about electricity and targeted the concept of conditions associated with the flow of electrical energy. The units each consisted of 12 analogous tasks, as described in TTable 5-13.

[17] Source: Australian Curriculum, Assessment and Reporting Authority (ACARA)

Table 5-13 Outline of units of learning

Task	Description	Role in the learning program	Role in research
1.1 1.2	Prior knowledge (2 tasks, second cued)	Engage and prior knowledge	Baseline transfer before learning activities
2	Language activity	Provide access to the language needed to communicate the targeted concept	Learning activities
3	Concept development – overarching concept	Site the targeted concept within the framework of a bigger idea	
4	Concept development – target concept	Present and develop the targeted concept	
5	Hands-on application of target concept	Apply the targeted concept in a hands-on context	
6	Interpretation of model of target concept plus self and peer feedback	Consider a different model of the targeted concept and give and receive feedback	
7	Application of concept in a real-world context	Further refine the targeted concept by applying it in a different context	
8.1 8.2	Post-test (same task as 1)	Demonstrate learning of targeted context	Transfer after learning activities
9	Application involving integrating other concept(s)	Extend learning by integrating it with other related concepts	Different forms of transfer
10	Application of analogous concepts from the big picture	Extend learning by considering other examples of the big idea	
11	Reproduce concept in a distracting context	Revisit concept by reproducing in a very different context	
12.1, 12.2	Application to real-world context after some time (uncued/ cued)	Revisit learning by applying it to a different real-world context	

The sequence of lessons is generally consistent with the 5 E's lesson sequence model. Hands-on, practical tasks were difficult to provide for the earthquakes unit and requests for more featured in student feedback. In response, Task 9 in the electricity unit was developed as a hands-on task, though still serving the same function as in the earthquake unit.

The materials addressed some of the issues raised by the pilot study. The second task was a language activity to give students access to the language needed to communicate and think about the targeted science concepts. Both peer feedback (activity 6) and self-assessment opportunities (activities 3-6) were included, allowing students to revise their thinking in the light of the targeted science concepts presented.

5.3.2.2.2 Teacher materials

Teacher materials included a PowerPoint presentation, an accompanying running sheet detailing the procedure for each lesson, and a set of videos explaining the targeted learning. There was also an introductory video explaining their role in the research to students. The running sheet described the steps of the activity linked to the relevant slide. Without providing a script, there were suggested questions for class discussion and an indication of how the students should record their thinking. Teachers were invited to record their feedback on the activities. Except for consumables and equipment normally found in classrooms, all practical materials were provided.

The classroom materials are available in Appendix P.

5.3.2.2.3 Student materials

Student materials were a set of worksheets that provided information in text and image formats, instructions, task prompts and space for recording responses for each task. In addition, some included self-assessment tools and feedback opportunities.

The materials are available in Appendix P.

5.3.2.2.4 Data collection materials

5.3.2.2.4.1 Work samples

Student worksheets contained their observations and responses to the learning activities. These were collected at the end of each session to analyse evidence of transfer of learning.

5.3.2.2.4.2 Student feedback

Most worksheets also offered students an opportunity to provide feedback on the learning activities at the end of the lesson.

5.3.2.2.4.3 CLARA learning dispositions tool

CLARA (Crick Learning for Resilient Agency) is an online survey tool for measuring eight dispositions that have been shown to affect students' learning Deakin Crick et al. (2015). Students complete a 60 question online survey, and the associated analytics use their responses to calculate their learning power in eight dimensions on a 0 to 1 scale. These eight dimensions are shown in **Error! Reference**

source not found.[18]. In seven of these, a score of 1 represents an adaptive version of the disposition, i.e. one which predisposes the student to learn, while 0 represents a maladaptive version of that disposition. In the final dimension, orientation to learning, the adaptive version of open readiness is scored at 0.5, with both the extremes of 0 (rigid persistence) and 1 (dependent fragility) being maladaptive. The students in this study completed this survey after completing unit one and before starting Unit 2. Feedback was that while students took it seriously, they found the 60 plus questions in the online survey quite a marathon to complete.

Figure 5-6 Dimensions of learning power from (Deakin Crick et al., 2015)

Image removed due to copyright restriction. Original can be viewed in

Deakin Crick, R., Huang, S., Ahmed Shafi, A., & Goldspink, C. (2015). Developing resilient agency in learning: The internal structure of learning power. *British Journal of Educational Studies, 63*(2), 121-160. https://doi.org/10.1080/00071005.2015.1006574

5.3.2.2.4.4 Learning preferences survey

Initially, it was planned to collect three sets of data about student learning dispositions at three stages in the research – before the first unit, between the two units and after the second unit to investigate differences in these due to exposure to the units. However, due to changes in the operation of the survey providers and the university governance, it was not possible to collect

[18] More information about CLARA can be found on the University of Technology Sydney Centre for Connected Intelligence website.

before the first unit and for a while seemed unlikely that the between units stage data collection would go ahead either. To capture some data on student learning preferences, a 20 item pencil and paper survey was run with classes. The survey was administered by teachers, using a script and visual support to explain each item for which students then scored the degree to which they agreed with a related statement on a 4 point scale. When feedback from the first school (school A) indicated that the language of the items was challenging for many students, a second version addressing the same content but using simpler language was produced for the remaining three schools. Feedback from the teachers who used this was that student interest was high, and most seemed to understand the items. The survey materials are available in Appendix M.

5.3.2.2.4.5 Class culture

Teachers were asked to complete a class culture questionnaire (rows 6+ of Table 5-27) to investigate any differences between classes. The education system seldom seeks this information but is often provided by teachers in response to a casual question like *How is your class this year?* It is also discussed in staffrooms, at photocopiers and yard duty handovers and teachers perceive it has a big impact on the effectiveness of their learning programs.

Teachers also had the option of recording comments or feedback on the learning activities from their perspective. Many chose to pass this on orally or by email.

5.3.2.3 Data collection procedures

5.3.2.3.1 Transfer of targeted concept

Many classroom assessment tools look for the number of instances of successful transfer, such as correct answers out of 10, addressing the questions: *Did they transfer?* or *How often did they transfer?* In this study, the question was: *What did they transfer?* and evidence was gleaned from an expanded response to a single question. Expanded responses from single tasks have been found to produce better evidence for SOLO level determinations (Pegg & Tall, 2005). Expanded responses are a richer source of evidence of grounded transfer, which includes the full range of ideas transferred by students in response to the task prompt. In addition to summative assessment, expanded responses provide more information for teachers' formative assessment.

Student work samples were coded using the framework Table 5-14. In this framework, evidence of transfer of the targeted concept falls into three main categories:

- No evidence of any thinking relevant to the targeted concept (N);

- Evidence of general knowledge or everyday thinking which is relevant to the targeted concept but which is not the concept itself (G);
- Evidence of the science concept (S).

Each of these is divided into two subcategories to get the six categories in Table 5-14. These are not necessarily in order of complexity.

Table 5-14 Categories for describing evidence of transfer of the targeted concepts

Grounded transfer categories		
Code	Description	Example from earthquakes unit
NO	No new ideas – no response or reproduction of information from task prompt or context	*This picture shows there has been a serious earthquake because there is a lot of damage to the building*
NN	No relevant ideas – alternative threads, missed the point	*Adelaide is not likely to have an earthquake because we are a much bigger country*
GL	Limited general knowledge relevant to the concept – names or misconception	*Adelaide won't have an earthquake because of the fault lines*
GT	At least 1 piece of sound general knowledge relevant to the concept	*Adelaide is unlikely to have an earthquake because we don't have serious earthquakes here*
SL	Limited knowledge of the concept – name only or misconception	*Adelaide won't have an earthquake because of the tectonic plates*
ST	At least one piece of sound scientific knowledge relevant to the concept	*Adelaide is unlikely to have an earthquake because we are not close to the edge of a tectonic plate*

At times first four were collapsed into one category: NG – no engagement with the science concept.

5.3.2.3.2 Evidence of engagement

Evidence of student engagement with the tasks was sought from their feedback at the end of each task. The engagement framework of Fredricks et al. (2004) was used as the basis for the three primary coding levels. These were subdivided into categories generated from student responses, as shown in Table 5-15.

Table 5-15 Framework for encoding student engagement from responses to the question: "Any feedback?"

Engagement categories		
Engagement Dimension	Dimension Sub-category	Example
Behavioural	No response (NO)	Box blank
	No relevant response (NR)	Doodle or comment about something other than the learning task
	Yes or no only (NY)	*Yes or no*
Emotional	Positive (EP)	*Fun, interesting, cool, liked*
	Negative (EM)	*Not fun, boring, dull, didn't like*
Cognitive task-oriented	Task difficulty (TD)	*Hard, easy*
	Task clarity (TI)	*Confusing, clear*
	Task process (TP)	*Liked that it was practical*
	Task suggestions (TS)	*More fun, more hands-on*
Cognitive concept-oriented	Performance-oriented (CP)	*I answered the questions well; I didn't know the answers*
	Learning oriented (CJ)	*I learnt …, I didn't learn anything*

The two cognitive concept-oriented categories reflect the mastery/ performance goals framework of Barron and Harackiewicz (2001). Performance-oriented feedback described how well they had or had not done in their response to the task, while learning-oriented feedback referred to what they had or had not learnt.

5.3.2.4 Variables

5.3.2.4.1 Independent variable

Pedagogy was manipulated through the learning materials. The three versions of pedagogy in the pilot study were collapsed into two versions to maximise the sample sizes of each pedagogy group. These were:

5.3.2.4.1.1 A. Low challenge pedagogy -Tell and practice, bounded framing

Concepts were presented to students as the current learning topic, and understanding of these was necessary to do well in this term's science. They were explained to students before they were given the opportunity to apply them. The Unit 2 headset summary provided for teachers was, "This is about electrical energy transfer. It will be explained to you, and then you get a chance to apply it";

5.3.2.4.1.2 B. High challenge pedagogy – Productive struggle, expansive framing

Concepts were presented as useful in understanding how the world works and in their future education or work. Students were asked to consider and respond to a question within a given context before the science perspective was explained to them. They were then asked to compare their thinking with the science version. The Unit 2 headset summary for teachers was, "This is about the transfer of energy, using electrical energy as an example. You will get to problem solve, then the science will be explained, and you can compare your ideas with the science."

5.3.2.5 Dependent variable

The dependent variable was transfer of the targeted science concepts, measured as described in Table 5-14.

5.3.2.6 Extraneous variables

Learner dispositions (CLARA) and preferences (paper-based survey) were measured after Unit 1 and before Unit 2. Engagement was measured from feedback given at the end of many learning tasks.

5.3.2.7 Experimental design

Two matched classes were selected for each school. For school A, these were chosen randomly; for school B, there were only two classes available; for schools C and D, neighbouring classes whose teachers worked closely together were chosen. These eight classes are shown shaded in Table 5-16.

Table 5-16 Allocation of classes to experimental conditions.

(Shading identifies matched classes for each school.)

School	Class	Teacher	Pedagogy Unit 1	Pedagogy Unit 2
A	1	TA	B	B
	2	TA	A	A
	3	TA	B	A
	4	TA	A	B
B	5	TB	A	B
	6	TB	A	A
C	7	TC	B	A
	8	TC	A	B
	9	TC	A	A
D	10	TD	A	A
	11	TE	A	B
	12	TF	A	B

An AA/AB experimental design was used because it was not possible to match the degree of difficulty in learning the two different concepts. All of the eight matched classes received pedagogy A in the first unit. In the second unit, one randomly selected class from each matched pair received pedagogy B, while the other class received pedagogy A again. This design has two built-in controls. Firstly, the pre-test and post-test in each unit measured the difference in transfer associated with the learning program in each unit, that is, whether each student's targeted transfer had improved over the course of the learning activities. Secondly, the low challenge (AA) condition for units 1 and 2 measured the difference in transfer associated with the different targeted concepts, that is, whether it was harder to get transfer of electrical energy flow than tectonic plates.

5.3.2.8 Procedure

Ethics approval from Flinders University Social and Behavioural Research Committee and the state Department for Education and Child Development was sought and received (see Appendix Q). Fliers for expressions of interest were distributed to schools early in the school year. The researcher met individually with teachers to explain their involvement in the project and deliver consent forms, and again as they were ready to commence each unit.

Teachers taught the units in their normal allocated science lessons and had periodic face to face and email communication with the researcher to resolve any issues. Student work samples were collected from the school at the completion of each unit. The timing varied between different schools, depending on other commitments in the school program and how much time was allocated for science. One school began in term one and finished well before the end of term 2, while another did not start until term three and finished just before the end of the school year. The final task (Task 12) was completed by all participants in the last few weeks of the school year.

5.3.3 Results – factors affecting transfer

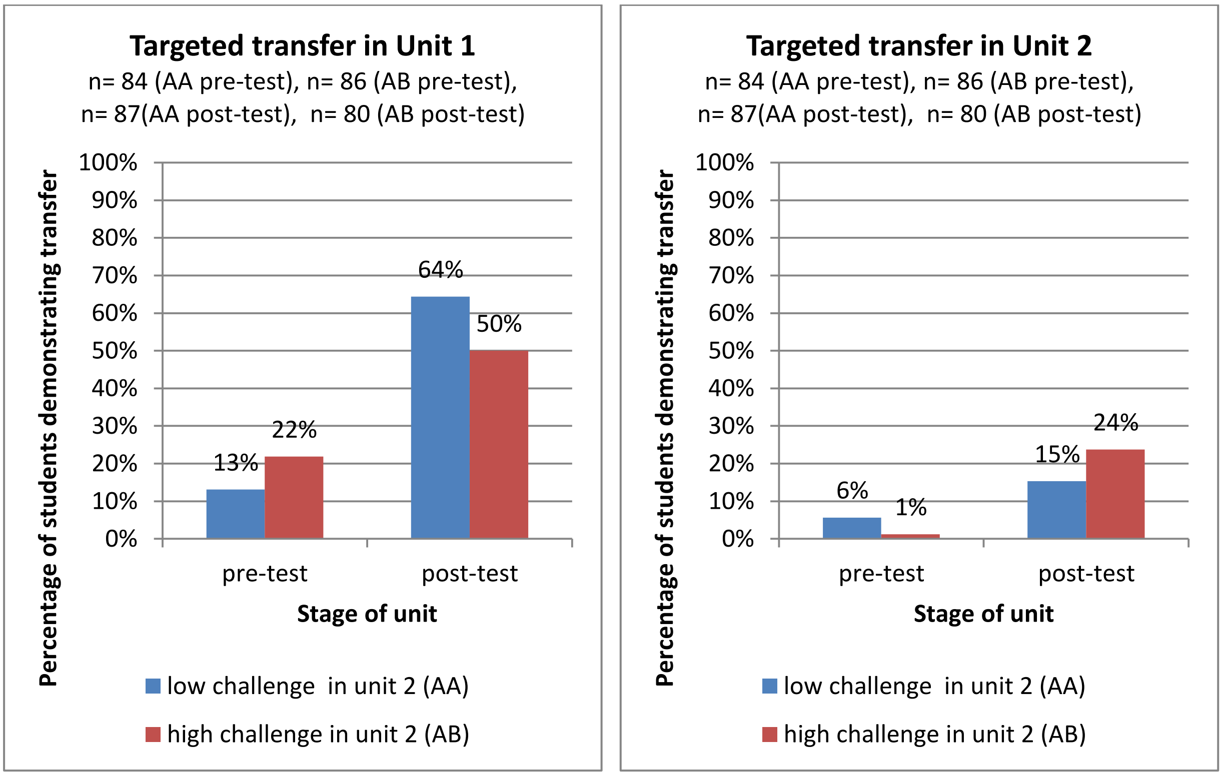
5.3.3.1 Pedagogy

Table 5-17 and **Error! Reference source not found.** summarise the effect of pedagogy on targeted transfer (as measured by ST level in Table 5-14) in each unit for low (AA) and high (AB) challenge pedagogy.

Table 5-17 Effect of pedagogy on targeted transfer in Units 1 and 2

Effect of pedagogy on targeted transfer in units 1 and 2				
	Unit 1 All low challenge pedagogy		Unit 2 AA low challenge; AB high challenge	
	Pre-test	Post-test	Pre-test	Post-test
AA	13%	64%	6%	15%
AB	22%	50%	1%	24%
Odds ratio AB/AA		.77		1.6

Figure 5-7 Effect of pedagogy on targeted transfer in units 1 and 2.
(Note that in Unit 1, both groups had low challenge pedagogy.)



The AA/AB design allows comparisons of the two groups with the same pedagogy and then with different pedagogy. In Unit 1, both the control (AA) and the experimental (AB) groups had low challenge pedagogy. Compared with the control group (AA), fewer students in the group which was to become the experimental group (AB) demonstrated targeted transfer in the post-test (odds ratio AB/AA = .78), despite slightly more doing so in the pre-test. The odds ratio below 1 suggests that these students were less effective learners with low challenge pedagogy, even though at the same year level in larger primary schools, students are generally assigned so that the classes are balanced in learning ability. An ANCOVA with the pretest as a covariate, indicated no significant difference in the post-test results for the two groups (results included in Appendix R) .

In Unit 2, the pre-test results indicated that experimental group (AB)started with slightly less targeted transfer compared to the control group (AA), but by the post-test, slightly more of them demonstrated targeted transfer (odds ratio AB/AA = 1.6). With high challenge pedagogy, this group of students were more effective learners than the low challenge group. Again, results from an ANCOVA, with the pre-test results as a covariate, indicated no significant differences in the post-test results in unit 2 (results shown in Appendix N). Thus, it seems that high challenge pedagogy offered a small, albeit non-significant, advantage in the number of students demonstrating targeted transfer.

In addition to the effect of pedagogy, **Error! Reference source not found.** also shows that the roportion of students showing targeted transfer was much less in Unit 2, even within the control group (AA) with low challenge pedagogy in both units. It seems that factors other than pedagogy influenced whether or not students transferred the targeted concept. Data on some of these factors was collected during the experiment, and this is presented in the next section, for each factor alone and in combination with pedagogy.

In summary, high challenge pedagogy resulted in a small, non-significant increase in the number of students demonstrating targeted transfer in the post-test task.

5.3.3.2 Other factors affecting transfer

5.3.3.2.1 How transfer is measured

Table 5-14 sets out the measurement of transfer in student responses. In the last two levels, students invoked the targeted concept, with the difference being that students coded SL invoked the concept in a limited way, whereas those coded ST were, in addition to invoking the concept, able to apply at least one sound aspect of the concept to the task context. The SL code indicates strategic transfer in that students recognised that the concept is appropriate in this context but were unable to demonstrate functional transfer (they did not successfully apply an aspect of the concept in this context). The ST code indicates that the student demonstrated both strategic and functional transfer because the concept was not cued by the context or the prompt. Examples of different levels are shown in the text box below.

Portraits of transferrers

This student has got it:

Moving tectonic plates explain where bad earthquakes occur – basically at the boundaries where two plates collide (strategic and functional)

This student knows about it, but she cannot do it yet:

Earthquakes – it's something to do with tectonic plates but I can't remember how it works (strategic only (limited))

This student has a misconception:

Earthquakes – it's to do with tectonic plates. If you are on a tectonic plate they you will get an earthquake if it collides with another. But if you aren't on a tectonic plate you don't get bad earthquakes (strategic only (misconception))

This student knows some relevant stuff but has not got the science concept we are going after:

Earthquakes happen if there have been earthquakes there before (No transfer of the targeted concept (general knowledge))

This student has missed the point:

Earthquakes depend on how close to the equator you are (no transfer of the targeted concept (alternative thread))

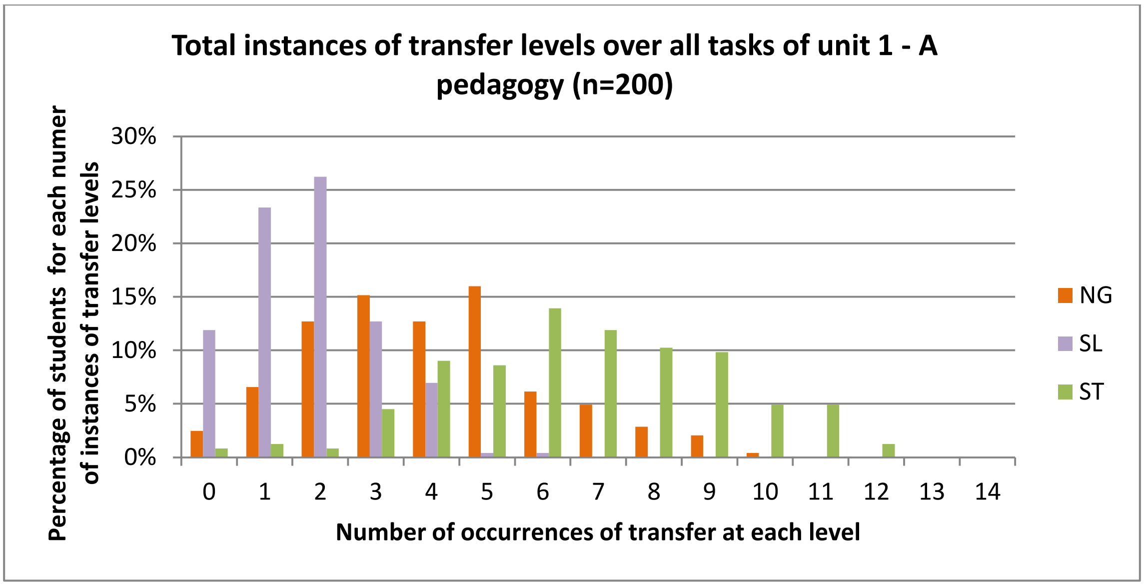
The transfer of strategic only (SL) and strategic plus functional (ST) aspects of the concept in the nine classes with tell and practice pedagogy in Unit 1 is shown in Table 5-18.

Table 5-18 Percentage of students demonstrating strategic and functional transfer in Unit 1 (low challenge pedagogy) n=190

Unit 1	Pre-test n=229	Post-test n=228	All tasks
No transfer of target concept (NG)	64%	23%	32%
Strategic only (SL)	20%	22%	14%
Strategic plus functional (ST)	16%	55%	54%

While the pre-test and post-test tasks did not cue the targeted concept and allowed students to demonstrate strategic transfer, this is not the case for every one of the twelve tasks. The SL category includes students whose work sample demonstrated limited transfer or misconceptions in those tasks where the targeted concept was cued. Across all tasks, the incidences of no transfer and limited transfer of the targeted concept (SL) were relatively low, but it is not clear how much these reflect the same few students consistently transferring at this level or whether they reflect a few instances over a larger number of students. The distribution of the number of times each student demonstrated these three transfer levels in Unit 1 is shown in **Error! Reference source not found.**.

Figure 5-8 Frequency of each level of transfer in Unit 1 low challenge pedagogy classes



Overall there were many instances of limited (SL) and functional (ST) transfer. Even though 36% of students demonstrated neither in the post-test task, 99% did so at some stage over the unit, and very few students had less than three instances of functional transfer. For limited transfer, very few students had more than four instances. Instances of no transfer of the targeted concept (NG) peaked higher than those of functional transfer, with many students demonstrating five or more.

The biggest change in Table 5-18 is the increase in strategic plus functional transfer at the expense of the no targeted transfer group, with the proportion of strategic only transfer remaining relatively constant between pre and post-test. Table 5-19 compares students' transfer levels in the pre and post-tests.

Table 5-19 Number (Percentage) of students with each of the nine possible combinations of pre and post-test strategic transfer in Unit 1 - low challenge pedagogy (n= 178).

(Shaded cells are students with the same pre-test and post-test levels.)

		Pre-test level (Task 1.1)		
		No targeted transfer (NG) (65%)	Strategic transfer only (SL) (19%)	Strategic & functional transfer (ST) (15%)
Post-test level (Task 8.1)	No targeted transfer (NG) (23%)	33(18%)	5(3%)	4(2%)
	Strategic transfer only (SL) (22%)	29(16%)	6(3%)	4(2%)
	Strategic & functional transfer (ST) (55%)	56(31%)	24(13%)	20(11%)

The majority of students (65%) started with no targeted transfer (NG), and of these, about half reached functional level (ST) transfer in the post-test. This compares with about two-thirds of those with at least limited (SL) or functional (ST) transfer in the pre-test, reaching targeted transfer in the post-test. Prior knowledge seemed to increase targeted transfer, but it was not a guarantee, as of the 34% of students who started with strategic or strategic plus functional transfer in the pre-test, about one in seven demonstrated none in the post-test.

Unit 2 allows comparison of the two pedagogies, which is shown in Table 5-20.

Table 5-20 Percentage of students demonstrating targeted transfer for high and low challenge pedagogy in Unit 2 (n=169)

Task	Low challenge (A)		High challenge (B)		Odds ratio AB/AA	
	Strategic transfer only	Strategic plus functional transfer	Strategic transfer only	Strategic plus functional transfer	Strategic transfer only	Strategic plus functional transfer
Pre-test	9%	6%	14%	1%	1.5	0.2
Post-test	19%	15%	20%	24%	1.1	1.6
All tasks	12%	30%	12%	20%	1.0	.7

While there is only a minor difference in strategic only transfer between the two pedagogies in the pre-test and no difference in the post-test or across all tasks, this is not the case for the strategic plus functional transfer. The small increase in transfer between pre-test and post-test associated with high challenge pedagogy was discussed earlier, but the picture is different when looking at all tasks. Here high challenge pedagogy is associated with a decrease in transfer, suggesting that the nature of the task also affects transfer.

Casting the net of targeted transfer wider to include the transfer of strategic aspects of the concept as well as functional aspects of the concept increased the number of incidences of targeted transfer detected in student work samples. However, whether students had high or low challenge pedagogy seems to have had little effect on this as the odds ratio for the strategic only transfer was close to 1 in the post-test. For the remainder of the analysis of this data, students who transferred only strategic aspects of the concept are not considered to have demonstrated targeted transfer of the concept unless otherwise stated. However, these students are included in measures of improvement in targeted transfer between the pre-test and post-test if their pre-test showed no targeted transfer (i.e. NG).

In summary, including transfer of strategic aspects increases the incidence of transfer. Pedagogy has little impact on this.

5.3.3.2.2 The concept

Not all curriculum concepts transfer equally easily. The difference in targeted transfer between the tectonic plates concept (Unit 1) and electrical energy flow concept (Unit 2) is demonstrated by the group of students with low challenge pedagogy in both units (Table 5-21, columns 2 to 5).

Table 5-21 Percentage of students with low challenge pedagogy demonstrating targeted transfer in pre and post-test for Units 1 and 2.

<table>
<tr><th rowspan="2">Concept</th><th colspan="2">Low challenge pedagogy (AA)</th><th colspan="2">Odds ratio (AA) (Unit 2/Unit 1)</th><th colspan="2">High challenge pedagogy (AB)</th><th colspan="2">Odds ratio (AB) (Unit 2/Unit 1)</th></tr>
<tr><th>Post-test</th><th>All tasks</th><th>Post-test</th><th>All tasks</th><th>Post-test</th><th>All tasks</th><th>Post-test</th><th>All tasks</th></tr>
<tr><td>Tectonic plates (Unit 1)
n=87 (AA); n=86 (AB)</td><td>64%</td><td>57%</td><td rowspan="2">.24</td><td rowspan="2">.53</td><td>50%</td><td>51%</td><td rowspan="2">.48</td><td rowspan="2">.40</td></tr>
<tr><td>Electrical energy flow (Unit 2)
n=85 (AA); n=80(AB)</td><td>15%</td><td>30%</td><td>24%</td><td>20%</td></tr>
</table>

The proportion of students transferring the electrical energy concept in Unit 2 post-tests was approximately one-quarter of tectonic plates in unit one for the post-tests and approximately one half across all tasks, illustrating the difficulty students have with transferring this concept. This difficulty is consistent with the view taken by Bell in her summary of New Zealand research on science teaching and learning that energy is “an abstract and difficult concept to teach and learn” *Bell (2005)* p79.

Table 5-21 columns 6-9 show that there was also a reduction in transfer of the electrical energy concept for the group who had high challenge pedagogy in Unit 2, but in the post-test, this was not to the same extent as was seen with the low challenge group. While the concept of electrical energy was transferred less across the board, the high challenge group did better or more accurately, less poorly with this harder concept.

From the perspective of the cognitive load theory (Sweller, 2010), the lower transfer of the electrical energy concept could be explained by its higher cognitive load. There is a larger number of elements in electrical energy (conductors, insulators, complete circuits, energy sources) compared with earthquakes (tectonic plates) which would account for some of the increase in cognitive load. Perhaps this is why many students stuck to the everyday elements of joined up wires and power sources.

In summary, changing the concept that was targeted from tectonic plates to electrical energy flow decreased the incidence of targeted transfer across the board, but less so for those with high challenge pedagogy.

5.3.3.2.3 The transfer task

The framework of Barnett and Ceci (2002) sets out to describe the differences between near and far transfer, which they break down into differences in content and context. Under the heading context, they identified six dimensions and qualitatively described each extreme as near (similar to the learning situation) or far (different to the learning situation). In this classroom study, four of these dimensions, domain, place, social grouping and authority, changed little between tasks, leaving only time and modality to describe differences between tasks which might correlate with differences in transfer. Klahr and Chen (2011) proposed a slightly different framework with three dimensions for classifying transfer distance for scientific reasoning in children. This framework compared the transfer situation with the original learning situation in task similarity, context similarity and time difference dimensions. Frameworks like these are useful when the researcher has information about the learning situation and the transfer task, but for classroom teachers, where student backgrounds and attendance are quite variable, this distinction is harder. For writers of test items for large cohorts, it is virtually impossible to take the original learning situations into account. For this study, the framework in Table 5-22 was developed to describe aspects of transfer tasks independently of learning tasks and the task environment.

Table 5-22 A classification of task factors relating to increasing difficulty of transfer.

(Numbers in brackets identify tasks from Unit 1, which are examples of each classification. Some tasks are omitted because they did not require transfer of the targeted concept.)

<table>
<tr><th>Task component</th><th>Aspect</th><th colspan="6">Increasing difficulty of transfer →</th></tr>
<tr><td rowspan="5">Context (setting)</td><td rowspan="2">Where is the task set?</td><td colspan="3" rowspan="2">Simplified real world (1.1,6)</td><td colspan="3">Real world (1.2,5,7,9,12.1,12.2)</td></tr>
<tr><td colspan="3">Abstract (4,11)</td></tr>
<tr><td>How familiar is the context to learners?</td><td colspan="2">Rehearsed</td><td colspan="2">Familiar but unrehearsed (1.1)</td><td colspan="2">Unfamiliar (1.2,4,5,6,7,9,11,12.1,12.2)</td></tr>
<tr><td>How is the task communicated?
Oral text diagram picture video concrete materials</td><td colspan="3">Familiar representation (1.1,4,7,9,11,12.1,12.2)</td><td colspan="3">Unfamiliar representation (1.2,5,6)</td></tr>
<tr style="display:none"></tr>
<tr><td rowspan="3">Prompt (response called for)</td><td>How much does the prompt cue the solution path (tell them what to do)?</td><td colspan="2">Scaffolded</td><td colspan="2">Cued (4,5,12.2)</td><td colspan="2">Learner selected (1.1,1.2,6,7,9,11,12.1)</td></tr>
<tr><td>What accountability is called for?</td><td>None</td><td colspan="2">Explain or Compare (1.2,4,5,6,11,12.1,12.2)</td><td colspan="2">Compare & explain (1.1,7,9)</td><td>Justify, evaluate</td></tr>
<tr><td>How essential is the targeted concept?</td><td colspan="3">Necessary (1.1,4,5,6,7,11,12.2,12.2)</td><td colspan="3">Helpful (1.2,9)</td></tr>
<tr><td>Solution path (how they get the response)</td><td>How complex is the solution path?</td><td colspan="2">Reproduce (4,11)</td><td colspan="2">Apply (1.1,1.2,5,6,7,9,12.2,12.2)</td><td colspan="2">Synthesize (invent)</td></tr>
</table>

This framework looks at three aspects of a task: the context in which it is set, the prompt which tells students how they need to respond and the solution path, the steps students go through to generate the response. The context and prompt are set by the task; the solution path varies between students and also between learners and experts. Experts effortlessly apply what learners must struggle to invent (Chi et al., 1981). In this study, instances of expert-like transfer were extremely rare, and they were included within the targeted transfer group. Some components are related to the students' familiarity with the context and its representation. While researchers and teachers can speculate about what might and might not be familiar to students, in reality, this will be different for every learner.

The effect on transfer of variations in the task is shown in Table 5-23.

Table 5-23 Analysis of task difficulty in Unit 1.

(The less difficult aspects are shown in green; more difficult in red. Task 10 did not require transfer of the targeted concept.)

Task	control group		Difficulty		
	n	% Transfer	Context	Prompt	Solution path
1.1	84	13%	Simplified	Learner selected, Compare	Apply
1.2	84	8%	Real word, emotive distraction, unfamiliar	Learner selected, helpful only	Apply
4	88	94%	Abstract	Learner selected	Reproduce
5	83	59%	Unfamiliar	Learner selected	Apply
6	79	67%	Unfamiliar	Learner selected	Apply
7	83	67%	Real world, unfamiliar	Learner selected	Apply
8.1	87	64%	Simplified	Learner selected, Compare	Apply
8.2	87	45%	Real word, emotive distraction, unfamiliar	Learner selected, helpful only	Apply
9	81	23%	Real word, emotive distraction, unfamiliar	Learner selected, compare, helpful only	Apply
10	81	80%	Real world	Learner selected	Apply
11	79	94%	Abstract, unfamiliar	Learner selected	Reproduce
12.1	79	82%	Real world, unfamiliar	Learner selected	Apply
12.2	79	77%	Real world, unfamiliar	Cued	Apply

Transfer was highest in tasks requiring reproduction rather than application of learning (Tasks 4, 11 & 12.1), and generally lower in tasks requiring application (Tasks 5,6,7,8.1,9 & 10). The exception is Task 12.1, where there was a high rate of transfer of the targeted science concept across all classes, surprising given the conditions that the task was completed under, i.e. online rather than on paper, in the last two weeks of the year and least three months after the unit was completed. Without cuing by the task prompt, most students transferred the concept of tectonic plates to explain the devastation caused by an earthquake in Japan. Some of this may be attributed to students' exposure to the concept in the intervening time, as during these months, there were two major earthquakes in Indonesia with a combined death toll of nearly 5 000. These would have been covered in media or current event programs that some students would have been exposed to.

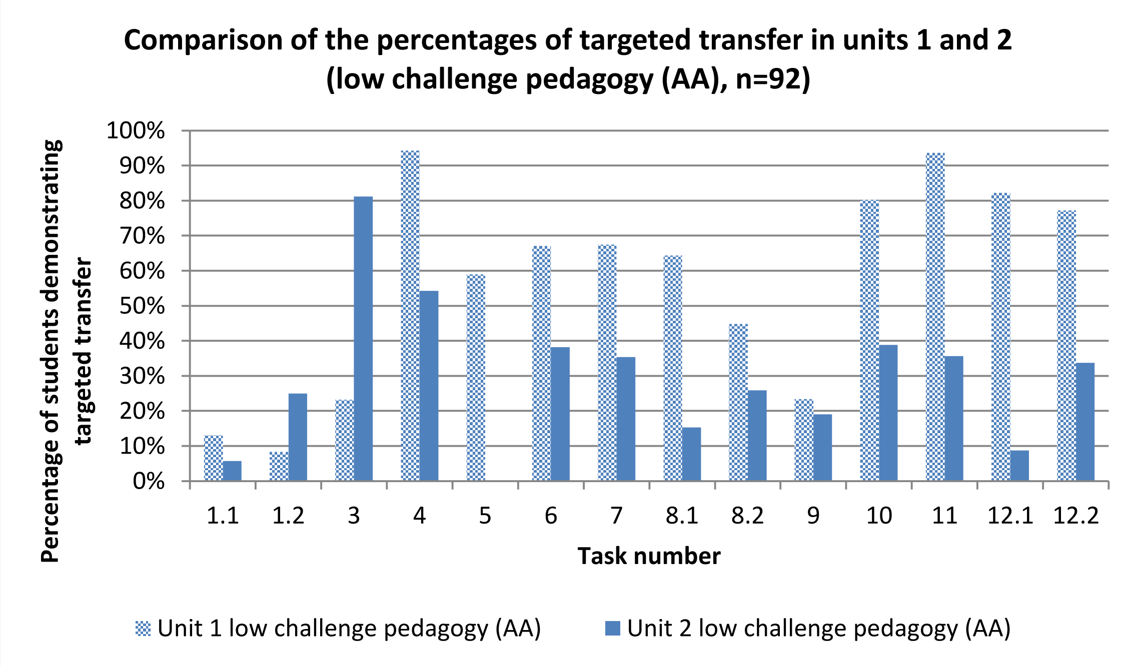
Distracting detail with an emotive component seems to be very effective in reducing transfer of the targeted concept. Tasks 1.2 (also 8.2) contained distracting detail about fake news, which seemed to trigger an emotional response from many students. This emotive detail was enough to decrease transfer of the tectonic plates concept in both the pre and post-test and increase the transfer of alternative threads from 13% in Task 8.1 to 32% in Task 8.2. For example, the alternative thread about the author's credentials was deemed by students to be both necessary and sufficient to answer the question. The tectonic plates concept was at best additional but often ignored.

Similarly, in Task 9, the conundrum of a storage site for nuclear waste overrode the tectonic plates cue in the context, and transfer was low (23%), with 35% of students transferring only alternative threads – mostly environmental safety. The concern is not that the alternative threads were transferred but that they were considered a sufficient response. Students' attention seems to have been hijacked by the emotive details, and they failed to engage the science causal web that would have been useful. The effect on transfer of learning of distracting or seductive details has received attention from several researchers. This finding on distracting detail supports that of Abercrombie et al. (2019) for preservice teachers, where seductive detail in contexts decreased transfer. They also noted that bolding to identify the relevant parts of the context counteracted the effect of seductive details. Wang, Ardasheva and Lin (2021) found that the effect of seductive details was most pronounced under low perceptual load, which in their study meant the absence of images along with the text. Manipulating contexts by removing illustrations or highlighting key aspects might improve performance on the immediate task and might be a useful scaffold for learning; however, it is less likely to prepare students to transfer in real-world scenarios, which may come with multimedia texts and where key aspects are not highlighted.

The two units were designed as a series of analogous tasks, with the context and prompt changed to address the different concepts while maintaining the purpose and structure of each task. Although transfer was lower in Unit 2, **Error! Reference source not found.** shows that the proportion of transfer across the tasks generally follows a similar pattern to Unit 1. This data is for the control group, with low challenge pedagogy in both units. The sample size for each task varies due to student absences.

Figure 5-9 Control group transfer of targeted concept across all tasks in units 1 and 2.

(Task 10 did not require transfer of the targeted science concept.)



Transfer is highest in the explain task (Task 4), which involved reproducing information immediately after it was presented and then decreased with later application tasks. The high percentage of transfer in Task 11, another reproduction task, showed that many students still had the concept even if they had not applied it in the previous tasks.

Some differences lie in the second task of the Unit 2 pre-test and post-test (Tasks 1.2 and 8.2). In the second unit, this was still set in the real world (involving fuses) but had no emotive, distracting detail, and an intervening task had primed the concept of electrical energy transfer. Consequently, more students transferred than in the first task (1.1.and 8.1). Task 9 involved a hands-on task on constructing a switch, again without the emotive detail of nuclear waste dumps, and the expected decrease in the number of students transferring the electrical energy concept was less.

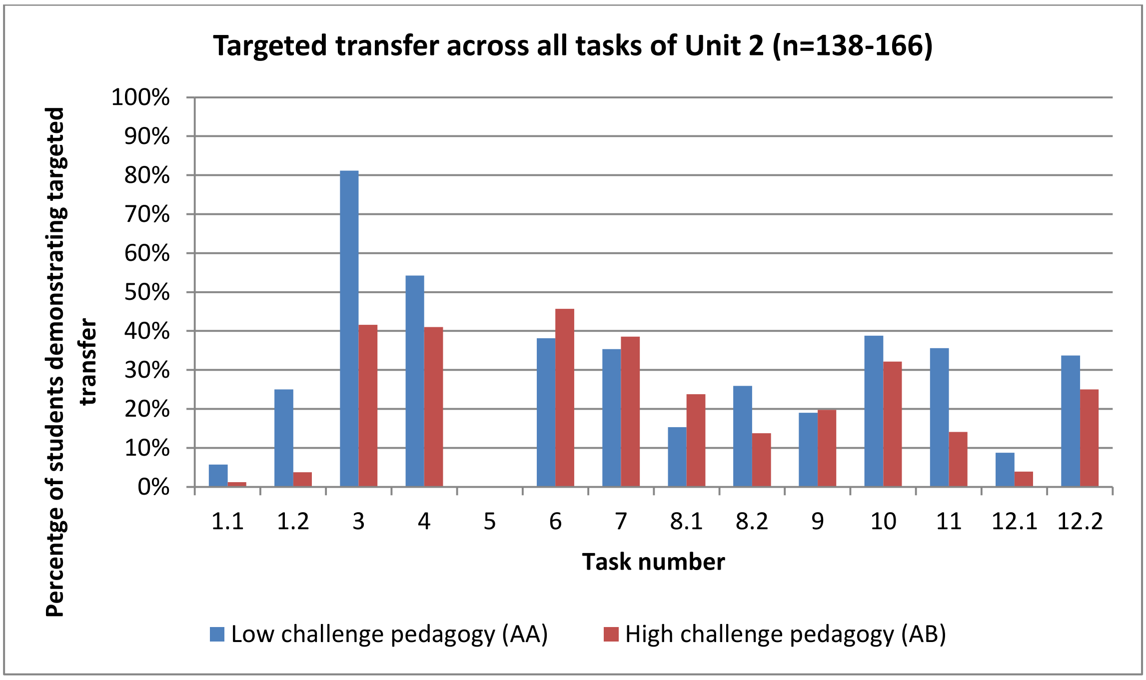
However, the biggest difference came in Task 12 – the online far transfer task. While for Unit 2, this was completed much closer to the learning tasks, the percentage of transfer of the electrical energy concept was as low as that of tectonic plates was high (9% for electrical energy and 82% for tectonic plates). Even with direct cuing of the electrical energy concept in Task 12.4, this only rose to 34%.

Most students saw the image of bent poles and broken wires on the ground as damaged power infrastructure, not as an interruption to the flow of electrical energy.

The targeted transfer across all tasks for the two different pedagogies in Unit 2 is shown in **Error! Reference source not found.**.

Figure 5-10 Percentage of students transferring across all tasks for low and high challenge pedagogy.

(Tasks 3 and 10 did not require transfer of the targeted science concept. N each task varies depending on absences on the day.)



The analysis of task difficulty for this unit is shown in Table 5-24.

Table 5-24 Analysis of task difficulty in Unit 2.

(The less difficult aspects are shown in green; more difficult in red. Tasks 3 & 10 (greyed) did not require transfer of the targeted concept. Transfer above the average for that task is indicated in blue. Transfer refers to the % transferring the targeted science concept.)

Task	Transfer		Difficulty		
	AA	AB	Context	Prompt	Solution path
1.1	6%	1%	Distracting context	Learner selected	Apply
1.3	25%	4%	Real word, unfamiliar	Cued	Apply
3	81%	42%	Abstract	Cued	Reproduce
4	54%	41%	Abstract	Learner selected	Reproduce
5	0%	0%	Unfamiliar, distracting hands on materials	Learner selected	Apply
6	38%	46%	Unfamiliar, distracting drama participation	Learner selected, option to respond to cue	Apply
7	35%	39%	Real world, unfamiliar	Learner selected	Apply
8.1	15%	24%	Distracting context	Learner selected,	Apply
8.3	26%	14%	Real-word, unfamiliar	Cued	Apply
9	19%	20%	Real-world, unfamiliar, distracting hands-on materials	Learner selected,	Apply
10	39%	32%	Real-world	Cued	Apply
11	36%	14%	Abstract, unfamiliar	Learner selected	Reproduce
12.3	9%	4%	Real-world, unfamiliar	Learner selected	Apply
12.4	34%	25%	Real-world, unfamiliar	Cued	Apply

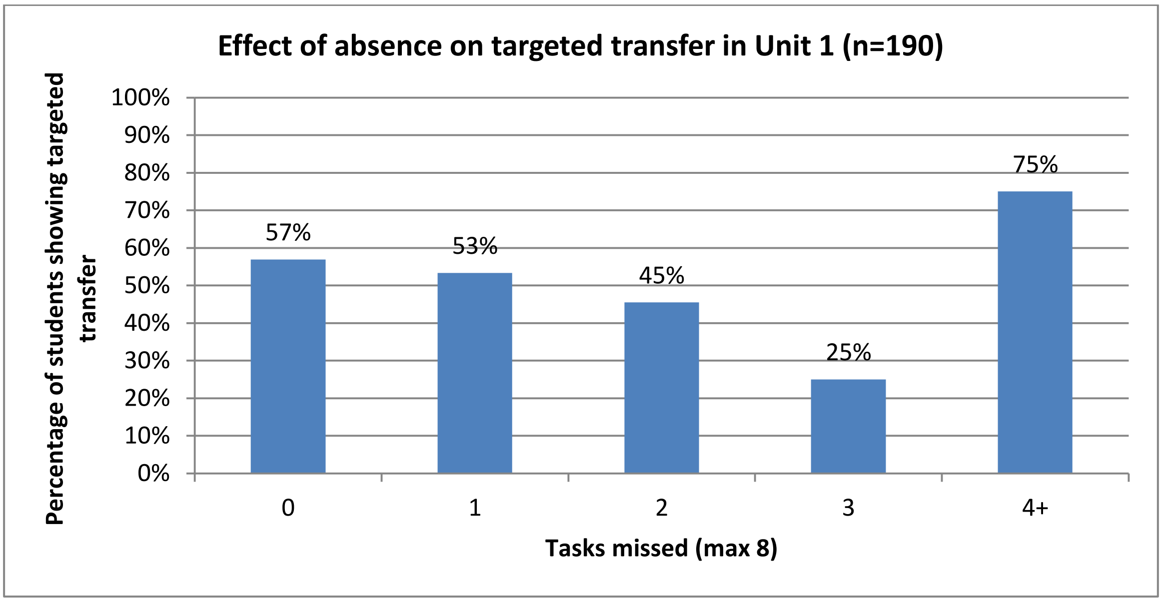
More students with low challenge pedagogy transferred in low challenge tasks, i.e. those requiring reproduction or when the learning was cued (Tasks 4, 8.3, 10, 11 & 12.4). There was a slight advantage for students with high challenge pedagogy in tasks with a higher degree of difficulty, such as Tasks 6, 7, 8.1 and 9 with unfamiliar distracting contexts. The distraction of the hands-on materials in Task 5 was so great that nobody transferred the concept of electrical energy, although since the order of Tasks 4 and 5 was reversed for different challenge pedagogy, the high challenge group (AB) students had not yet had the explanation for the concept. In this unit, when learning was assessed by transfer in real-world, distracting contexts, the high challenge pedagogy students did better, while for tasks requiring reproduction or where the concept was cued, low challenge pedagogy students did better. One explanation for this is that the high challenge pedagogy in this unit valued student thinking, so more students could think their way through in the face of distractions. The flip side is that high challenge students are less likely to reproduce cued learning in easier tasks and more likely to go their own way, often invoking alternative threads.

In summary, fewer students demonstrated targeted transfer in tasks with a higher degree of challenge, such as applying rather than reproducing concepts and distracting details in the context material. However, students taught with high challenge pedagogy did comparatively better than their peers with low challenge pedagogy in the more challenging tasks.

5.3.3.2.4 Absence from class

The justification for reporting and enforcing student attendance is that absence from school interferes with educational outcomes. Despite the high attendances reported at these schools (see Table 5-12), not all students were present for all eight tasks offered before the post-test. The effect their absence had on their demonstration of targeted transfer in Unit 1 is shown in **Error! Reference ource not found.**.

Figure 5-11 Effect of absence from class on targeted transfer in Unit 1 (all low challenge pedagogy) n=190



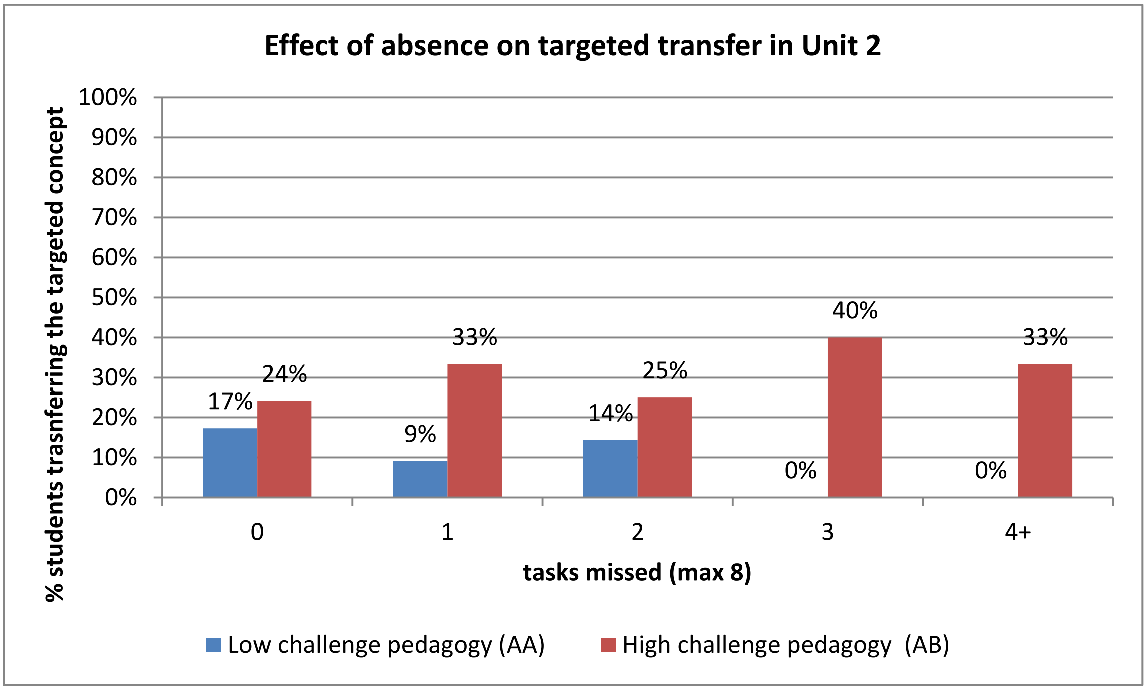
In Unit 1, with the less abstract concept and low challenge pedagogy, there was minimal difference in the proportion of students demonstrating targeted transfer between those who were present for all tasks and those who missed one or two tasks. For those missing more than two tasks, the apparent increase in transfer should be interpreted with caution due to very low sample sizes and the possibility that others assisted these students because they had missed so much.

The low overall rate of targeted transfer in Unit 2 means that the number of students who missed tasks but still showed targeted transfer in the post-test was quite small. Table 5-25 and **Error! Reference source not found.** compares the effect of absence on students with different pedagogies.

Table 5-25 Effect of absence from class and pedagogy on targeted transfer in unit 2

	Number of tasks missed				
Pedagogy	0	1	2	3	4
AA	10/58 (17%)	1/11(9%)	2/14 (14%)	0/14 (0%)	0/0
AB	14/58 (24%)	2/6 (33%)	2/8 (25%)	1/8 (25%)	1/3 (33%)

Figure 5-12 Effect of absence on targeted transfer in Unit 2 for low (AA) and high (AB) challenge pedagogy. n=182



Again the sample sizes for students missing tasks are low, but these results suggest that transfer of the concept with high challenge pedagogy was less affected by absence from class than with low challenge pedagogy.

In summary, within the limitations of this small sample size, it appears that missing a task was less of a setback for students with high challenge pedagogy.

5.3.3.2.5 The class and teacher

The variation in transfer of the targeted concept in the Unit 1 post-test is shown in Table 5-26. Data for the three classes with high challenge pedagogy have been greyed and does not contribute to the other averages.

Table 5-26 Variation between classes, schools and teachers in the Unit 1 post-test targeted transfer.

(Table row shading distinguishes the four schools.)

CLASS	Number of students	Targeted transfer for class (Unit 1 post-test)	School	Targeted transfer for school (Unit 1 post-test)	Teacher	Targeted transfer for teacher (Unit 1 post-test)
1	14	50%	A	53%	A1	56%
2	22	59%				
3	17	47%				
4	21	52%				
5	30	43%	B	57%	B1	57%
6	24	75%				
7	1	86%	C	71%	C1	68%
8	12	67%				
9	16	69%				
10	25	56%	D	46%	D1	56%
11	23	48%			D2	48%
12	17	29%			D3	29%
ALL	192	55%				

There was little variation in the percentage of students demonstrating targeted transfer between the two classes taught by the same teacher in schools A and C. There was substantial variation between the two classes taught by the same teacher in school B, suggesting that factors of the classes themselves contributed to this variation. For the three classes in school D, science was taught by their regular class teacher rather than a specialist science teacher. Classes 10 and 11, with similar outcomes in targeted transfer, shared a teaching space and the two teachers worked closely together. Class 12 worked in a separate space with their class teacher, and their targeted transfer was substantially lower.

The class culture survey was returned by two teachers who taught five classes between them. Their responses are presented in Table 5-27.

Table 5-27 Targeted transfer and teacher responses to class culture survey.

(Responses in red indicate unproductive behaviour or learning traits.)

Transfer	Class 5		Class 6		Class 7		Class 8		Class 9	
Unit	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2
Pedagogy challenge	Low	High	Low	Low	High	High	Low	High	Low	Low
Transfer in post-test tasks (Task 8.1)	43%	33%	75%	17%	86%	0%	67%	25%	69%	6%
Transfer in reproduction task (Task 4)	100%	44%	100%	65%	100%	67%	85%	80%	94%	47%
Teacher responses										
*Compared to the other classes, how is the **behaviour** of class …*										
Compliant (1) or challenging(4)	1		4		1		3		1	
Responsive (1) or unresponsive (4)	1		1		1		1		1	
distractible (4) or focused (1)	1		4		1		4		1	
Supportive (1) or tolerant (2) or competitive (3) or quarrelsome (4)	2		2		3		4		1	
Dependent (4) or independent (1)					1		3		1	
Behaviour (4) or learning (1) dominates	1		1		1		4		1	

Compared to the other classes, how is the ***attitude*** to learning of class ...					
Disengaged (4) or engaged (1)	1	1	1	3	1
Unquestioning (1) or questioning (4)	1	1	1	3	1
avoid (4) or accept (1) challenge	1	1	1	4	1
dominated by a few children (4) or able to share attention among class (1)	1	1	1	4	1
Anything to add?	*I think a lot of the class culture is dependent on the expectations set up by the 'regular' teacher. Seeing the class for 50 minutes once a week makes it very hard to set up and reinforce your own set of expectations – if you spend too long focusing on that aspect of classroom management it leaves very little room for content to be delivered.*		*In this class there are many high achievers and often need extending. They are very interested in science and we have many in-depth discussions about other topics. There are also a few NEP students in this class who need extra support.*	*This class has a large group of boys who team up together to be disruptive. When split up and completing a hands on activity they are more engaged.*	*This class work very well together. They are positive leaners and always eager to try new things*

Class 6 was identified by its teacher as being more difficult to manage than the matched class 5. In Unit 1, when both classes had low challenge pedagogy, class 6 had more students demonstrating targeted transfer than class 5. However, in Unit 2, and again with low challenge pedagogy, Class 6 had less students transferring than class 5, which had high challenge pedagogy. This is despite them doing better in reproducing the concept after it was explained in Task 4. In the second unit with more challenging content, low challenge pedagogy seems to have worked against the class with challenging behaviour.

In school C, class 8 was also identified as having more challenging behaviour and in addition, less adaptive attitudes to learning. Compared to their matched class 9, these students did similarly with low challenge pedagogy in Unit 1, but with high challenge pedagogy in Unit 2, more of them demonstrated targeted transfer in both the post-test and the reproduction tasks. It would seem that high challenge pedagogy was a particular benefit to more challenging classes.

Of particular interest is class 7, described by their teacher as having a positive and somewhat competitive approach. With high challenge pedagogy, the percentage of students transferring the targeted concept was the highest of all classes in Unit 1. However, in the post-test task of Unit 2, they adopted a functional view (using everyday ideas to explain what worked), and only one out of the six students invoked the concept of electrical energy at all. Across all tasks of Unit 2, their transfer was again the highest of all classes, pointing to the limitations of a single summative assessment task.

Class-related factors that affect learning outcomes have been identified in research literature before. Fauth, Wagner, Bertram, Gollner, Roloff, Ludtke, Polikoff, Klusmann and Trautwein (2020) found considerable variation in how different classes rated the same teacher and documented interactions between ratings of teacher quality, student motivation and student learning outcomes. This class culture factor is more than the sum of the individual students. Variation between teachers has been identified as a substantial contributor to variation in learning outcomes (Hattie, 2009, p. 219). This study suggests that there might be some variation between the classes themselves, making at least a partial contribution to the between-class variation and that high challenge pedagogy has potential with difficult to manage classes. Interestingly, the suggestion that high challenge pedagogy might assist learners in difficult to manage classes runs contrary to the commonly given behaviour management advice, which is to keep learning activities s imple and straight-forward – much closer to tell and practice. For learners who are bored or disenchanted with their failure to succeed with tell and practice pedagogy, high challenge pedagogy might offer a refreshing change.

In summary, there is evidence that factors related to the classes themselves might have contributed to variation in the percentage of students demonstrating targeted transfer, and a suggestion that high challenge pedagogy may improve targeted transfer in difficult to manage classes.

5.3.3.2.6 Learner dispositions

CLARA learning disposition data was collected for three of the four schools involved (a total of 131 students). Although CLARA measures learner dispositions on a continuous scale between 0 and 1, to summarise results, each was divided into three groups: a high group (CLARA score >.66), a midrange group (.33 <= CLARA score <.66), and a low group (CLARA score <.33). For this particular group of students from schools with relatively high ICSEA values, the means of each disposition were well above the normalised mean of .5 for the whole population. Their summary data is shown in Table 5-28.

Table 5-28 Distribution of students in high, mid-range and low groups for each CLARA disposition (n=131)

CLARA disposition	Participants mean	n high group (>.66)	n midrange group (>.33,<=.66)	n low group (<=.33)
Mindful agency (MA)	.629	55	72	4
Sense making (SM)	.724	89	38	4
Creativity (Cr)	. 633	58	67	6
Curiosity (Cu)	.609	53	71	7
Belonging (Be)	.801	105	22	4
Collaboration (Co)	.69	84	45	2
Hope and optimism (HO)	.714	80	49	2

Because of low numbers, the group with low CLARA scores was not included in the following analysis of this data.

The effect on targeted transfer of high and mid-range CLARA scores for each of 7 CLARA learner dispositions is shown in Table 5-29, **Error! Reference source not found.** and **Error! Reference source not found..** Data is given for two measures of transfer – transfer of the targeted concept (ST) and improvement in transfer. The latter expands the concept of transfer to include those students who improved from no transfer (NG) to limited transfer (SL). It does not include students with limited transfer (SL) that had not changed from the pre-test or those at the higher level in the pre-test. Expanding the definition of targeted transfer had the effect of increasing the number of students for further analyses.

Table 5-29 Percentage of students with high and medium CLARA levels demonstrating targeted transfer and improvement in transfer in Unit 1.

CLARA disposition	CLARA disposition level	Transfer of the targeted concept (ST)	Improvement in transfer
Mindful agency (MA)	high >.66 (n=41)	24 (59%)	27 (66%)
	mid >.33 (n=64)	39 (61%)	47 (73%)
Sense making (SM)	high >.66 (n=71)	40 (56%)	48 (68%)
	mid >.33 (n=34)	23 (68%)	25 (74%)
Creativity (Cr)	high >.66 (n=45)	27 (60%)	29 (64%)
	mid >.33 (n=59)	34 (58%)	43 (73%)
Curiosity (Cu)	high >.66 (n=40)	27 (68%)	29 (73%)
	mid >.33 (n=62)	33 (53%)	41 (66%)
Belonging (Be)	high >.66 (n=84)	50 (60%)	58 (69%)
	mid >.33 (n=21)	13 (62%)	15 (71%)
Collaboration (Co)	high >.66 (n=68)	40 (59%)	48 (71%)
	mid >.33 (n=39)	24 (62%)	26 (67%)
Hope and optimism (HO)	high >.66 (n=60)	37 (62%)	45 (75%)
	mid >.33 (n=47)	27 (57%)	29 (62%)

Figure 5-13 Targeted transfer in Unit 1 for mid and high CLARA disposition scores.

(See Table 5 30 for a key to CLARA dispositions. N=131)

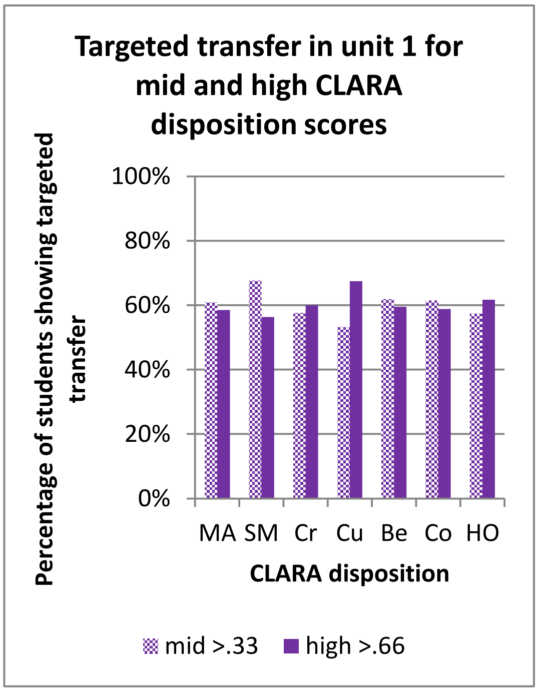
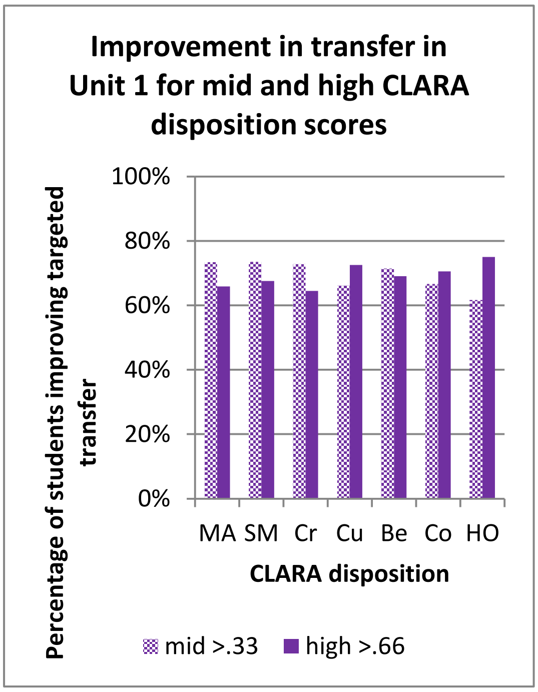


Figure 5-14 Improvement in targeted in Unit 1 for mid and high CLARA disposition scores.

(See Table 5 30 for a key to CLARA dispositions. N=131)



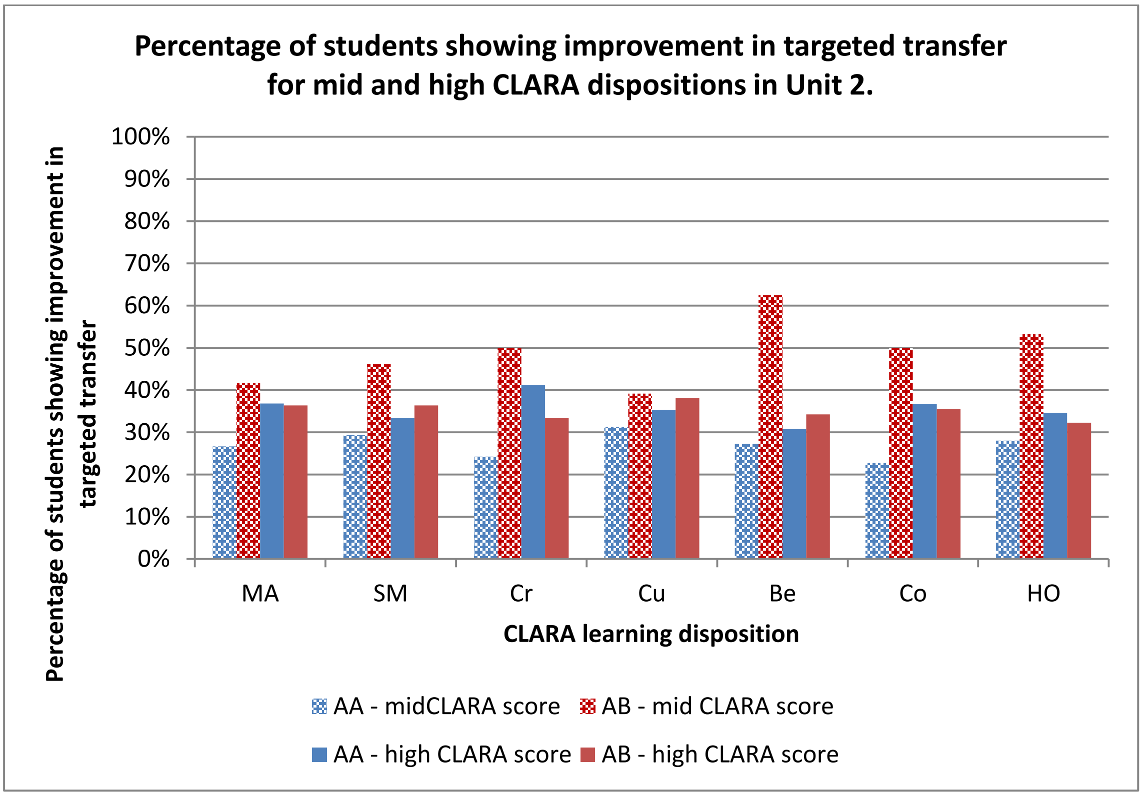
With a few exceptions, there was little difference in the rates of targeted transfer or improvement in targeted transfer for high and mid-range dispositions. Counter-intuitively, given that high CLARA scores represent adaptive dispositions, there seems to have been a slight advantage for students with mid-range scores in mindful agency and sense-making.

In Unit 2, overall targeted transfer was low (19% for the post-test task), and so the data about the effect of pedagogy and CLARA dispositions in Table 5-30 and **Error! Reference source not found.** is for those students who had improved their level of transfer between the pre-test and post-test, i.e. those who started at NG level and reached SL or ST or started at SL and reached ST. It does not include those who started at ST or SL and finished at SL. Overall this represents 37 students or about 33%.

Table 5-30 Percentage of students improving targeted transfer for each CLARA score and pedagogy in Unit 2

CLARA disposition	CLARA disposition level	Low challenge pedagogy (AA)		High challenge pedagogy (AB)		Odds ratio
		n	Improved transfer (%)	n	Improved transfer (%)	AB/AA
Mindful agency (MA)	high >.66	19	37%	22	36%	1.0
	mid >.33	30	27%	24	42%	1.6
Sense making (SM)	high >.66)	33	33%	33	36%	1.1
	mid >.33	17	29%	13	46%	1.6
Creativity (Cr)	high >.66	17	41%	24	33%	0.8
	mid >.33	33	24%	20	50%	2.1
Curiosity (Cu)	high >.66	17	35%	21	38%	1.1
	mid >.33	32	31%	23	39%	1.3
Belonging (Be)	high >.66	39	31%	38	34%	1.1
	mid >.33	11	27%	8	63%	2.3
Collaboration (Co)	high >.66	30	37%	31	35%	1.0
	mid >.33	22	23%	14	50%	2.2
Hope and optimism (HO)	high >.66	26	35%	31	32%	0.9
	mid >.33	25	28%	15	53%	1.9

Figure 5-15 Effect of the combination of CLARA dispositions and pedagogy on improvement in targeted transfer



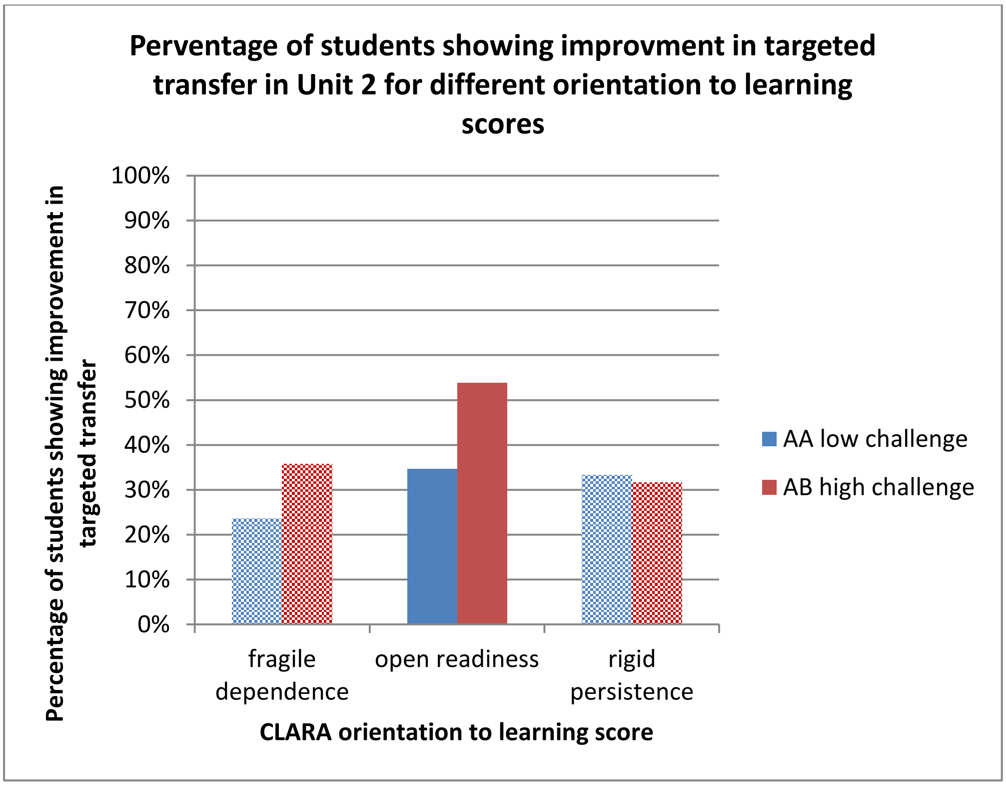
Again for students with high scores on CLARA learning dispositions, there was little difference in improvement in targeted transfer between the two pedagogies (odds ratios around 1.0). However, for students with only average scores in all CLARA dispositions except curiosity, high challenge pedagogy resulted in more improvement in targeted transfer, compared to the mid-range CLARA group with low challenge pedagogy. This difference was most pronounced in belonging, hope and optimism and collaboration (odds ratios closer to 2.0), and improvement in targeted transfer was higher than for both of the high score CLARA groups.

The final CLARA learning disposition is presented differently from the others. For CLARA Orientation to Learning, a score of 0.5 is optimal between rigid persistence as the score decreases to zero and dependent fragility as the score increases to 1.0. The improvement rates for the low, mid and high range groups of this disposition are shown in Table 5-31 and **Error! Reference source not found.**.

Table 5-31 Effect of CLARA Orientation to learning score on improvement in targeted transfer

CLARA disposition level	Low challenge pedagogy		High challenge pedagogy		Odds ratio
	n	Improved transfer (%)	n	Improved transfer (%)	AB/AA
High >.66	17	24%	14	36%	1.5
Mid >.33	26	35%	13	54%	1.6
Low >0	9	33%	19	32%	0.9

Figure 5-16 Effect of CLARA Orientation to Learning score on improvement in targeted transfer



High challenge pedagogy was associated with slightly higher improvement in transfer rates for the optimal open readiness group and the fragile dependence group, while there was little difference between the two pedagogies for the rigid persistence group.

There appears to have been an interaction between pedagogy and some learning dispositions which affected transfer. High challenge pedagogy seems to have acted differentially, with higher rates of improvement in transfer for students with only average disposition scores while still not disadvantaging those with high disposition scores. To investigate this group of students with CLARA scores in the average range but who did better than expected with high challenge pedagogy, available data about engagement, self-assessment and learner preferences were analysed.

For students with high CLARA disposition scores, pedagogy made little difference to the number of students demonstrating improvement in transfer of the targeted science concept. However, for the group of students with average CLARA scores in Belonging, Collaboration, Hope and Optimism and Curiosity, high challenge pedagogy resulted in more students showing improvement in transfer of the targeted concept.

5.3.3.2.7 Engagement

Feedback provided by students was analysed for evidence of their engagement with the task. Tasks 2 to 6 of Unit 2 had different low and high challenge pedagogy versions. In these tasks, 168 (69%) of students gave feedback at least once, providing 711 instances of feedback. These were scored using the engagement framework described in 5.3.2.3.2, and the frequencies of the five engagement categories for students who showed improvement in targeted transfer and those who did not are shown in Table 5-32 and **Error! Reference source not found.** and **Error! Reference source not found.**.

Table 5-32 Percentage of students giving feedback in each engagement category.

(Percentages do not add up to 100% because some students gave feedback from multiple categories for one task)

Engagement dimension	Percentage of students with improvement in transfer giving feedback in each category		Percentage of students with NO improvement in transfer giving feedback in each category	
	AA (n=23)	AB (n=30)	AA (n=60)	AB (n=44)
Behavioural (B)	13%	3%	22%	16%
Emotional (E)	65%	70%	48%	50%
Cognitive task-oriented (CT)	70%	70%	50%	61%
Cognitive concept-performance oriented (CP)	4%	13%	3%	14%
Cognitive concept-learning oriented (CJ)	22%	50%	15%	16%
Average incidences of feedback per student	1.7	2.1	1.4	1.5
	1.9		1.5	

Figure 5-17 Percentage of students with improvement in targeted transfer for each engagement category.
(See Table 5 32 for key to engagement category codes.)

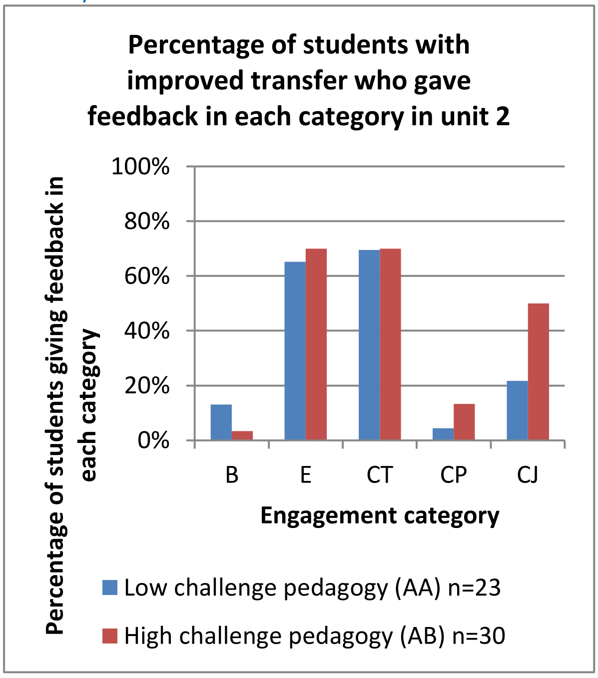
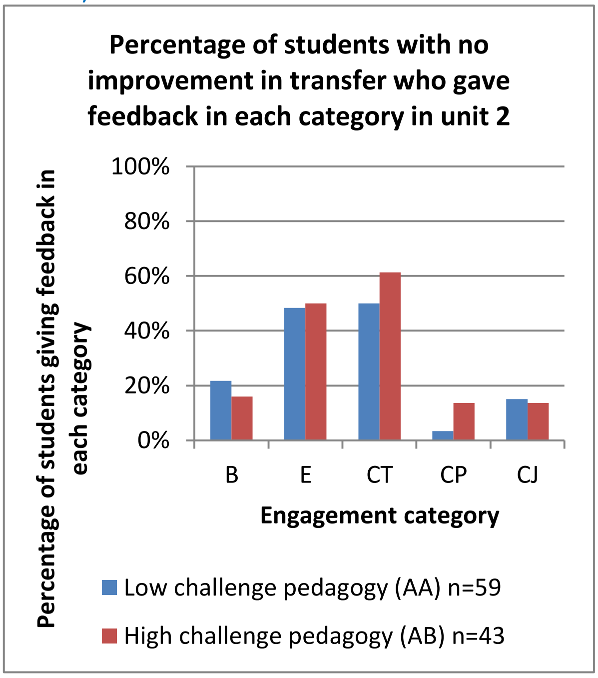


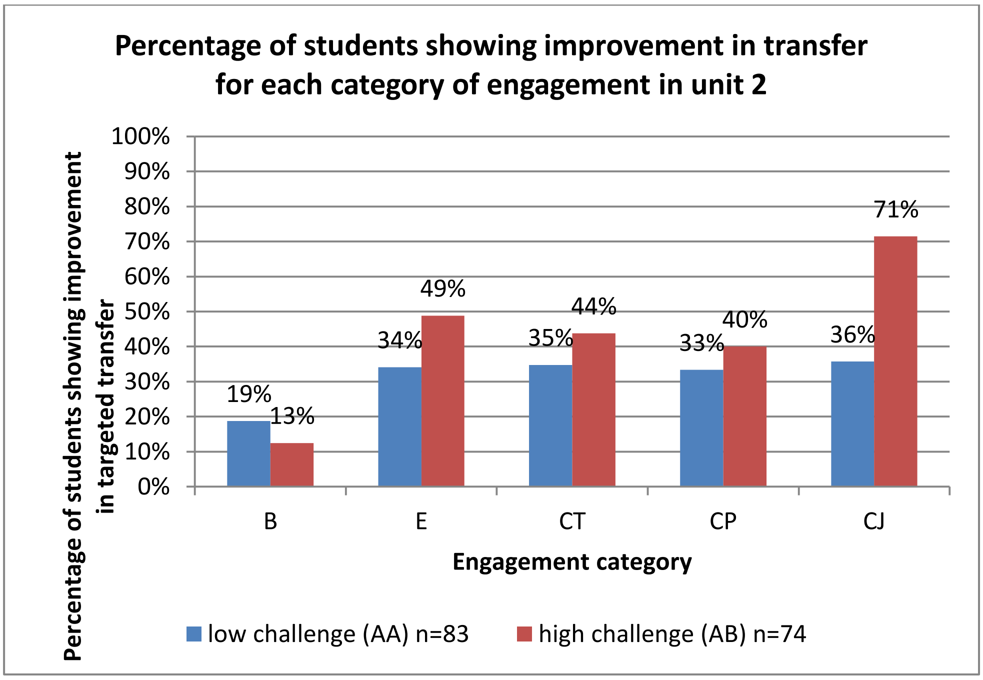
Figure 5-18 Percentage of students with NO improvement in targeted transfer for each engagement category.
(See Table 5 32 for key to engagement category codes.)



For all feedback categories except behavioural, students who showed no improvement in transfer provided less feedback than those who did show improvement. The most common engagement categories for both pedagogies were emotional and cognitive task-oriented; most students wrote about what they did or did not like about the tasks. The least frequent engagement dimensions were behavioural and cognitive performance-oriented, the latter indicating that few students offered an evaluation of their written task record. The most notable difference in engagement between the two pedagogy groups is the higher incidence of cognitive concept-oriented engagement for the group of students who improved in targeted transfer with high challenge pedagogy. This incidence of cognitive concept-oriented feedback was more than double the incidence for low challenge pedagogy, suggesting that high challenge pedagogy supports this kind of cognitive engagement with the concept to be learnt, which in turn supports transfer. This connection is further illustrated by the percentage of students showing improvement in targeted transfer for each dimension of engagement shown in **Error! Reference source not found.**.

Figure 5-19 Percentage of students showing improvement in transfer for each engagement category.

(See table Table 5 32 for key to engagement category codes.)



While the improvement rates for the first four engagement dimensions are roughly similar for high and low challenge pedagogy, for those students who gave evidence of cognitive concept engagement, the improvement rate is double for the high challenge pedagogy group compared with the low challenge pedagogy group.

Thus, two groups of students showed better than expected improvement in transfer with high challenge pedagogy – those with average scores of CLARA learning dispositions and those who gave cognitive concept-oriented feedback. Combining these two factors would generate seven separate data sets, one for each of the CLARA learning dispositions, and allow investigation of the effect on targeted transfer of interactions between mid and high CLARA scores, engagement and pedagogy. However, as only 30 students demonstrated targeted transfer, in Unit 2, there is not enough data to take this analysis any further.

In summary, the group of students with high challenge pedagogy who demonstrated improved targeted transfer gave twice as much cognitive concept-oriented feedback as those who did not improve and compared with both low challenge groups. High challenge pedagogy seems to have been associated with an increased focus on the concept.

5.3.3.2.8 Self-assessment

While it could be argued that self-assessment is not a factor directly affecting transfer of learning, it is included here as it may give some insight into differences between the two pedagogies. Students completed a self-assessment task after the pre-test and post-test. In the pre-test self-assessment, 83% of the 160 students completing the task gave a self-assessment that agreed with the transfer level assigned by the researcher on the evidence in their task response. The remaining 16% were evenly divided between those who rated their understanding higher than the evidence provided and those who rated it lower. This percentage of students giving accurate self-assessments fell to 60% in the post-test, with the remainder evenly split between over and underestimating. This data is shown in Table 5-33.

Table 5-33 Accuracy of student self-assessment in pre-test and post-test of unit 2

	High	Accurate	Low
Pre-test	8%	83%	9%
Post-test	19%	60%	21%

When pedagogy is taken into account the results are shown in **Error! Reference source not found.** and **Error! Reference source not found.**.

Figure 5-20 Accuracy of self-assessment in Unit 2 pre-test (n=182)

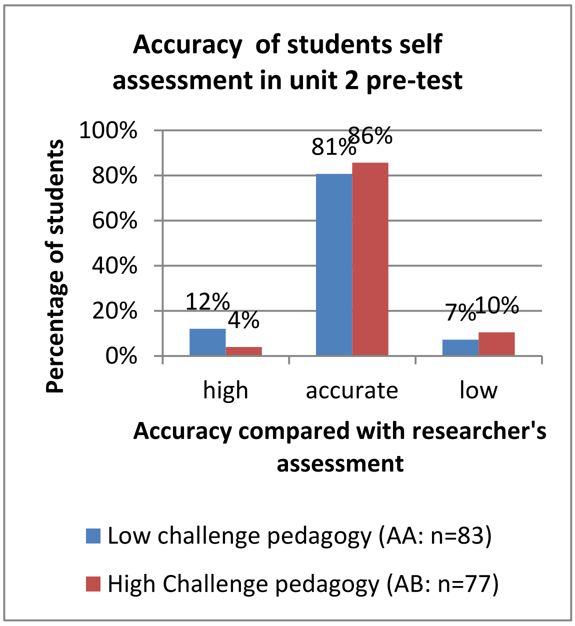
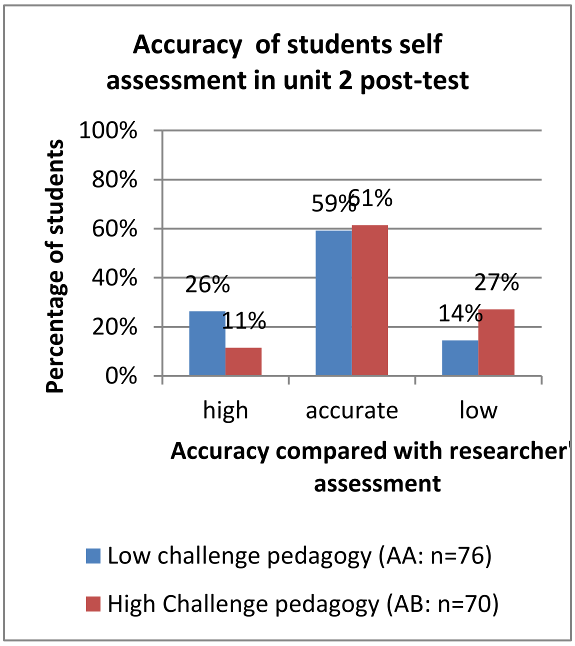


Figure 5-21 Accuracy of self-assessment in Unit 2 post-test. (n=158)



For the majority of students whose self-assessment was accurate, there was little difference between low and high challenge pedagogy groups. However, for the remainder, students with low challenge pedagogy more often rated themselves higher than their evidence suggested, while those in the high challenge pedagogy group more often rated themselves lower. There was some suggestion of this in the pre-test, but the pattern is more pronounced in the post-test, where about double the low challenge group overestimated and the high challenge group underestimated their achievement.

Although self and peer assessment opportunities were part of the learning program, individual teacher feedback on students' work samples was not given, as this would have introduced another variable in the experimental design. The fact that 40% of students did not rate their level of understanding accurately after the learning activities underscores the importance of feedback from an expert's point of view. In addition, there is some suggestion that the feedback provider needs to be aware of different issues for each kind of pedagogy, i.e. a possible tendency for students to overestimate their level of understanding with low challenge pedagogy and underestimate it with high challenge pedagogy.

In summary, students with low challenge pedagogy tended to overestimate their understanding, while those with high challenge pedagogy tended to underestimate it.

5.3.3.2.9 Learner preferences

Students' preferences for tell and practice or productive struggle were measured by two items in the Learning Science survey conducted before productive struggle pedagogy was introduced into the research units. Their responses, measured on a 4 point scale, are shown in Table 5-34, **Error! Reference source not found.** and **Error! Reference source not found.**.

Table 5-34 Percentage of students showing improved transfer in Unit 2 post-test for responses to the Learning Science items.

Item number	Item	Student responses					
	At the start of the lesson, would you prefer:	Pedagogy challenge	n	Nearly always (A)	Often (O)	Some-times (S)	Almost never (N)
4	The teacher explains the idea and asks questions to check your understanding?	Low (AA)	55	0%	30%	36%	0%
		High (AB)	51	20%	41%	50%	0%
	Odds ratio	AB/AA		-	1.17	1.4	-
5	The teacher asks questions to get you thinking about the idea and then explains it?	Low (AA)	55	7%	11%	67%	0%
		High (AB)	51	67%	14%	35%	20%
	Odds ratio	AB/AA		8.11	1.06	0.46	-

Figure 5-22 Percentage of students showing improvement in targeted transfer for tell and practice preferences

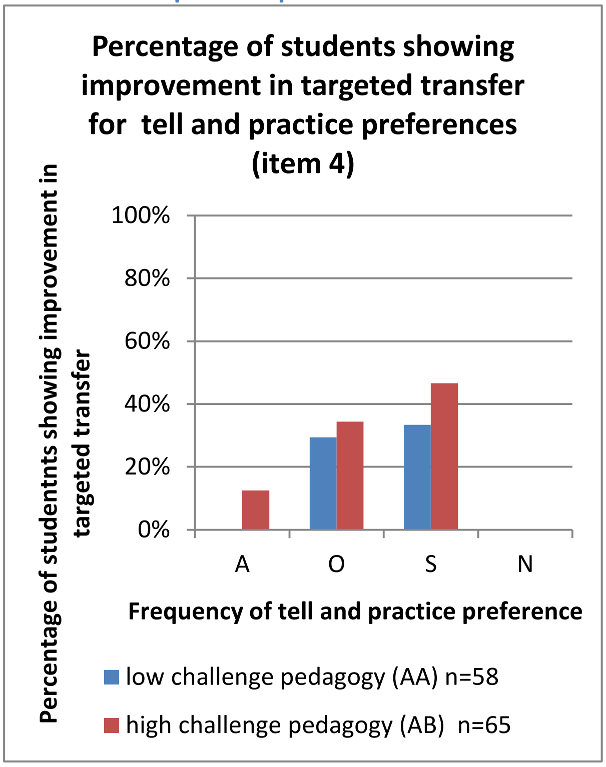
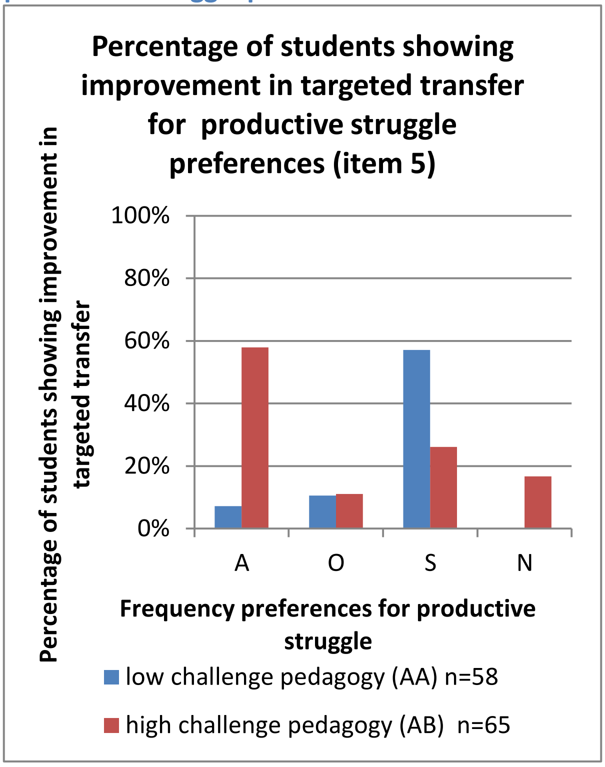


Figure 5-23 Percentage of students showing improvement in targeted transfer for productive struggle preferences



For tell and practice preferences (Item 4, **Error! Reference source not found.**), the percentage of tudents showing targeted transfer increased as their preference for tell and practice pedagogy decreased, and there was less difference between the low and high challenge pedagogy. Curiously, even students with strong preferences for tell and practice did better with high challenge pedagogy.

The most noticeable difference between high and low challenge pedagogy is that for students with a strong preference for productive struggle, eight times as many showed improvement in targeted transfer with high challenge pedagogy (Item 5, **Error! Reference source not found.**), while for those ith a weaker preference for productive struggle did better with low challenge pedagogy. In other words, students did better with their preferred style of pedagogy.

In summary, stronger preferences for tell and practice pedagogy were associated with lower percentages of students demonstrating improvements in targeted transfer in the post-test, while stronger preferences for productive struggle were associated with the higher percentages of targeted transfer with high challenge pedagogy. Conversely, weaker preferences for productive struggle were associated with more students improving in targeted transfer for low challenge pedagogy.

5.3.3.3 Learning trajectories

Learning trajectory here refers to student progress in transfer outcomes as they move through the sequence of learning activities offered in each unit of work. These are not a factor affecting transfer of learning, but indicators of students' progress through the unit. In the pilot study (Chapter 5.2.3.6), there was evidence that learning trajectories continued to change well after the classroom unit's end, so this section investigates learning trajectories in this study by looking at evidence of transfer of the targeted science concept across each unit. The key stages in the unit are outlined in Table 5-35.

Table 5-35 Key phases of the sequence of learning activities.

(0 = no evidence of transfer of the targeted science concept; 1 = evidence of transfer of the targeted science concept.)

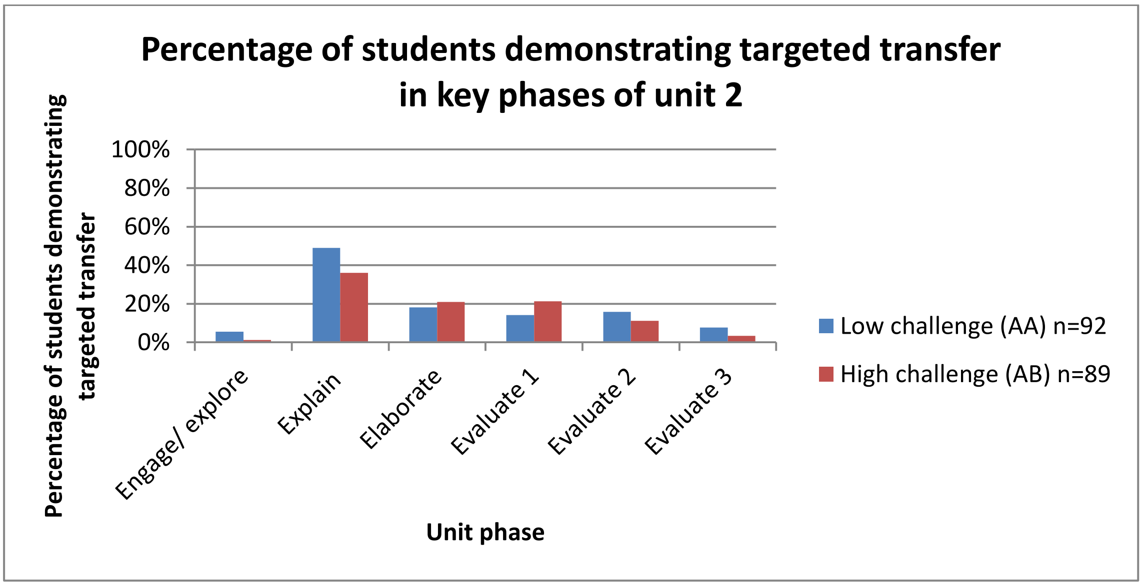
Tasks	Unit phase	Description of activity	example trajectory
1.1	Engage/ explore	Apply the concept in an unfamiliar context (prior knowledge)	0
4	Explain	Reproduction concept explained immediately before	1
5-7	Elaborate	Application of the concept in a range of contexts and modes	1
8.1	Evaluate 1	Same task as 1.1 (summative evaluation)	0
8.2-9,11	Evaluate 2	Application of concept in a range of near and far transfer tasks	1
12.2	Evaluate 3	Application of the task in a far transfer task	0

The final column of Table 5-35 describes a possible learning trajectory for a single student. This student did not transfer the targeted concept in the prior knowledge task - but did so straight after the explain phase and in at least one of the elaborate phase tasks. They did not transfer it in the unprompted summative assessment task (Task 8.1) nor the final far transfer task (Task 12.3) but did so in at least one of the other evaluate phase tasks. In the field trial, 23 students (9% of all students) took this trajectory.

Error! Reference source not found. illustrates the average learning trajectory through Unit 2 for the high and low challenge groups.

Figure 5-24 Frequency of transfer of the targeted science concept at key phases in Unit 2.

(Tasks 5-7 and 8.2-11 show the average incidence of ST for the set of tasks.)



Targeted transfer was highest in the explain phase, where students were reproducing material presented immediately before and lower over the rest of the unit. There are some small differences between the high and low challenge groups but no indication of any variation in trajectory within each group.

For each of the six key phases in the learning sequence, there are two possibilities (either they did or did not provide evidence of transferring the targeted concept), and so the learning trajectory described in Table 5-35 is just one of a total of 64 possible pathways through the unit. Amongst the 244 students who participated in the study, there were 34 different learning trajectories, all shown in Table 5-36.

Table 5-36 Percentages of students demonstrating each possible learning trajectories.

(Grey text indicates trajectories not represented in this sample of students. Blue text indicates higher percentages in the low challenge pedagogy group and red higher percentages in the high challenge pedagogy group. The total percentage column refers to all participants, including the 44 who were not part of the matched classes (BB or BA pedagogy).)

Learning trajectory							Percentage of students		
No.	Phase (Task)						TOTAL	AA	AB
	Engage (1.1)	Explain (4)	Elaborate (5-7)	Evaluate 1 (8.1)	Evaluate 2 (8.2-11)	Evaluate 3 (12.4)			
t1	1	1	1	1	1	1	0%	0%	0%
t2	1	1	1	1	1	0	0%	1%	0%
t3	1	1	1	1	0	1	0%	0%	0%
t4	1	1	1	1	0	0	0%	0%	0%
t5	1	1	1	0	1	1	1%	1%	0%
t6	1	1	1	0	1	0	0%	0%	0%
t7	1	1	1	0	0	1	0%	0%	1%
t8	1	1	1	0	0	0	0%	0%	0%
t9	1	1	0	1	1	1	0%	0%	0%
t10	1	1	0	1	1	0	0%	0%	0%
t11	1	1	0	1	0	1	0%	0%	0%
t12	1	1	0	1	0	0	0%	0%	0%
t13	1	1	0	0	1	1	0%	0%	0%
t14	1	1	0	0	1	0	0%	1%	0%
t15	1	1	0	0	0	1	0%	0%	0%
t16	1	1	0	0	0	0	0%	0%	0%
t17	1	0	1	1	1	1	0%	0%	0%
t18	1	0	1	1	1	0	0%	0%	0%
t19	1	0	1	1	0	1	0%	0%	0%
t20	1	0	1	1	0	0	0%	0%	0%
t21	1	0	1	0	1	1	0%	0%	0%
t22	1	0	1	0	1	0	0%	1%	0%
t23	1	0	1	0	0	1	0%	0%	0%
t24	1	0	1	0	0	0	0%	0%	0%
t25	1	0	0	1	1	1	0%	0%	0%
t26	1	0	0	1	1	0	0%	0%	0%
t27	1	0	0	1	0	1	0%	0%	0%
t28	1	0	0	1	0	0	0%	0%	0%
t29	1	0	0	0	1	1	0%	1%	0%
t30	1	0	0	0	1	0	0%	0%	0%
t31	1	0	0	0	0	1	0%	0%	0%
t32	1	0	0	0	0	0	0%	0%	0%
t33	0	1	1	1	1	1	2%	3%	2%

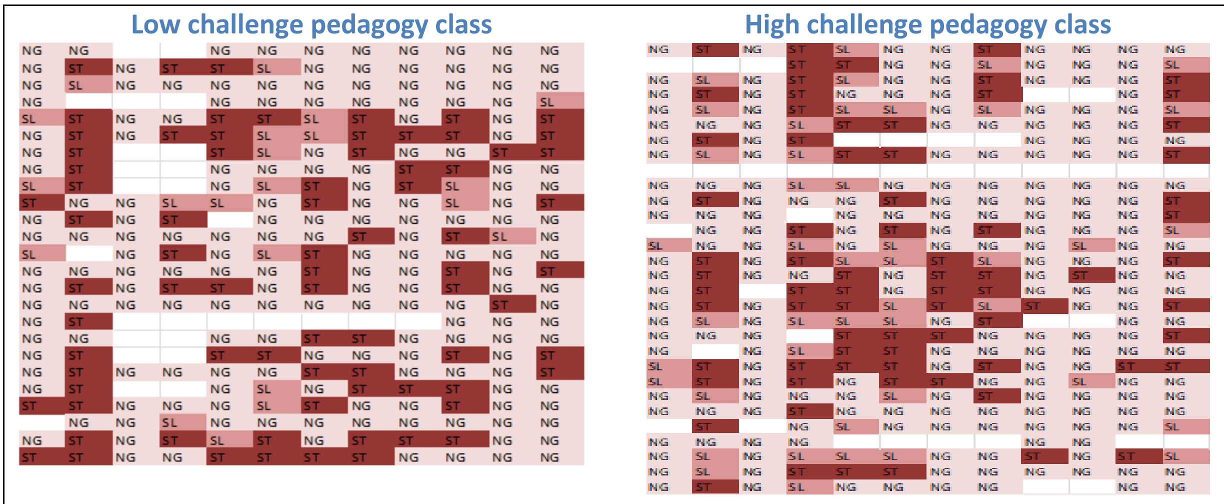
Learning trajectory							Percentage of students		
No.	Phase (Task)						TOTAL	AA	AB
	Engage (1.1)	Explain (4)	Elaborate (5-7)	Evaluate 1 (8.1)	Evaluate 2 (8.2-11)	Evaluate 3 (12.4)			
t34	0	1	1	1	1	0	3%	2%	5%
t35	0	1	1	1	0	1	1%	0%	0%
t36	0	1	1	1	0	0	1%	1%	1%
t37	0	1	1	0	1	1	6%	8%	6%
t38	0	1	1	0	1	0	9%	10%	7%
t39	0	1	1	0	0	1	0%	0%	0%
t40	0	1	1	0	0	0	5%	8%	4%
t41	0	1	0	1	1	1	0%	0%	0%
t42	0	1	0	1	1	0	0%	0%	0%
t43	0	1	0	1	0	1	0%	0%	1%
t44	0	1	0	1	0	0	1%	1%	1%
t45	0	1	0	0	1	1	1%	2%	0%
t46	0	1	0	0	1	0	3%	7%	1%
t47	0	1	0	0	0	1	1%	2%	1%
t48	0	1	0	0	0	0	4%	2%	7%
t49	0	0	1	1	1	1	1%	1%	1%
t50	0	0	1	1	1	0	3%	2%	4%
t51	0	0	1	1	0	1	1%	0%	2%
t52	0	0	1	1	0	0	1%	0%	2%
t53	0	0	1	0	1	1	3%	2%	2%
t54	0	0	1	0	1	0	9%	9%	8%
t55	0	0	1	0	0	1	1%	2%	1%
t56	0	0	1	0	0	0	10%	2%	16%
t57	0	0	0	1	1	1	0%	1%	0%
t58	0	0	0	1	1	0	1%	0%	2%
t59	0	0	0	1	0	1	0%	0%	0%
t60	0	0	0	1	0	0	1%	1%	0%
t61	0	0	0	0	1	1	1%	2%	0%
t62	0	0	0	0	1	0	7%	9%	5%
t63	0	0	0	0	0	1	2%	3%	2%
t64	0	0	0	0	0	0	18%	14%	20%
all students							244	92	108
Number of different trajectories taken							34	28	24

The most common trajectory, taken by 18%, had no indication of transfer of the targeted concept in any of the activities, followed by the trajectory where the only evidence of transfer of the targeted concept was in one of the elaborate phase activities (10%). Thirteen trajectories each accounted for less than 1% of all students. Thus, as in the pilot study, there are multiple paths to transfer and failure to transfer.

When the trajectories of groups with different pedagogies are compared, there are differences in the frequencies of some trajectories. Despite having nearly 20% more students, the high challenge group (AB) had a smaller range of trajectories (18 from 108 students compared to 24 from 92 students). In particular, there were higher numbers of students with t64 (no evidence of targeted transfer in any task), T56 (evidence of targeted transfer only in the elaborate phase) and t34 (evidence of targeted transfer in all phases except prior knowledge and the far transfer task) in this high challenge group. In this study, students with high challenge pedagogy (AB) lay at the extremes – they either showed good transfer or no transfer. In contrast, students low challenge pedagogy (AA) were more represented in trajectories t40 (evidence of targeted transfer only in the explain and elaborate phases), t46 (evidence of targeted transfer only in the explain and at least some of the evaluate phase) and t62 (at least some evidence of targeted transfer in the evaluate phase). In general, these were the low challenge tasks.

The individual learning trajectories for the students in two classes in the same school and with the same teacher is shown in **Error! Reference source not found.**.

Figure 5-25 Unit 2 learning trajectories for two classes



Columns represent the 16 tasks, and rows represent 25 of the 80 students. Transfer is colour coded as follows:

Key

Dark red	Strategic and functional transfer
Mid red	Strategic transfer only
Pale pink	No transfer of the targeted concept
White	Absent for task

Transfer down the columns follows the patterns described in **Error! Reference source not found.**, ith some tasks showing a low number of students transferring, e.g. the first column from the left shows transfer in the prior knowledge task (Task 1.1), and others a higher rate, e.g. the second column from the left in each class shows transfer in the explain task (Task 4). Less clear are patterns across the rows. While some students show higher levels of transfer overall, it often comes and goes in unpredictable ways.

Students in these classrooms sat in table groups, and in these circumstances, it would be rare for responses to tasks to be completed in silence so that sharing of ideas among at least the table group members would be relatively common. Evidence of this was also found in Chapter 4.4.4.4.1. In addition it would be expected that these groups would change if not weekly (i.e. between every task or couple of tasks), then after a few weeks. Changing group members gives students opportunities to try out a range of ideas from others, and in the absence of targeted feedback from the teacher, both those ideas consistent and those inconsistent with the targeted science concept may persist for some time. The takeaway message for teachers is not that sharing ideas, especially those inconsistent with the science concept, should be discouraged but that the advantages and limitations of each should be discussed with the class and targeted feedback to individual students.

In summary, in the most common learning trajectories, students demonstrated targeted transfer at the explain and elaborate phases.

5.3.3.4 Results summary

The experiment was designed to investigate the effect on targeted transfer of changing the amount of challenge in teachers' pedagogy. In addition to the measure of targeted transfer, data was collected on 13 aspects related to the students, the learning and the learning program. These have been described in the preceding sections (5.3.3.1 to 5.3.3.3) and are summarised in Table 5-37. Their impact on the proportion of students demonstrating targeted transfer has been summarised firstly alone and secondly in combination with the level of challenge in the pedagogy.

Table 5-37 Summary of the findings from the field trial data set.

Factor	Conditions	Effect alone	With pedagogy
Pedagogy	High/ low challenge	Increase in targeted transfer for challenging tasks	N/A
How transfer is measured	Strategic/ strategic + functional	Increase in measured targeted transfer if strategic only transfer is included as well	Pedagogy challenge level had minimal effect on strategic only transfer; its main effect is to increase sample size of those showing successful transfer
Concept	Tectonic plates/ electrical energy flow	Less targeted transfer in the post-test with electrical energy flow compared to tectonic plates	Smaller decrease in targeted transfer in the post-test tasks with high challenge pedagogy.
Transfer task	Context/ prompt/ solution path	Less targeted transfer in more challenging tasks (requiring application of concept or with distracting detail)	More targeted transfer in challenging tasks with high challenge pedagogy; reverse for low challenge tasks
Absence from class	Present for all/ missed task	Slight decrease in targeted transfer with any absence from class	No observed decrease in targeted transfer with any absence from school with high challenge pedagogy
Class and teacher	Class Teacher School	2.3 fold variation in targeted transfer in post-test between classes and teachers; 1.5 fold between schools	N/A
Clara dispositions	Mid-range/ high range	Little difference in targeted transfer in post-test between high and mid-range scores for any CLARA disposition	Increase in targeted transfer in post-test for mid-range CLARA disposition scores with high challenge pedagogy. Little difference in targeted transfer for high range CLARA disposition scores between the two pedagogies.
Engagement	Behavioural Emotional Cognitive: task performance journey	Students who improved in targeted transfer in the Unit 2 post-test gave more feedback in all categories except behavioural	High challenge students who improved in targeted transfer in the Unit 2 post-test gave three times as much cognitive feedback addressing their learning journey.
Self-assessment	Accurate Overestimate underestimate	60% of students gave accurate self-assessment in the Unit 2 post-test. The remaining were evenly split between over and underestimating.	High challenge students tended to underestimate and low challenge tended to overestimate their achievement by a factor of 2.

Learner preferences	tell and practice preference/ productive struggle preference	Optimal targeted transfer for students with midrange preference for tell and practice and mid to high range preference for productive struggle.	Students with strong preference for productive struggle showed more targeted transfer with high challenge pedagogy. Students with a weak preference for productive struggle showed more targeted transfer with low challenge pedagogy. High challenge pedagogy did not disadvantage students with a strong preference for tell and prectice
Learning trajectories	ST at Engage Explain Elaborate Evaluate 1 Evaluate 2 Evaluate 3	Most targeted transfer in the explain, elaborate and evaluate 2 phases. These were low challenge tasks.	High challenge students showed more polarised trajectories – either a lot or little targeted transfer. Low challenge students showed more consistently average trajectories.

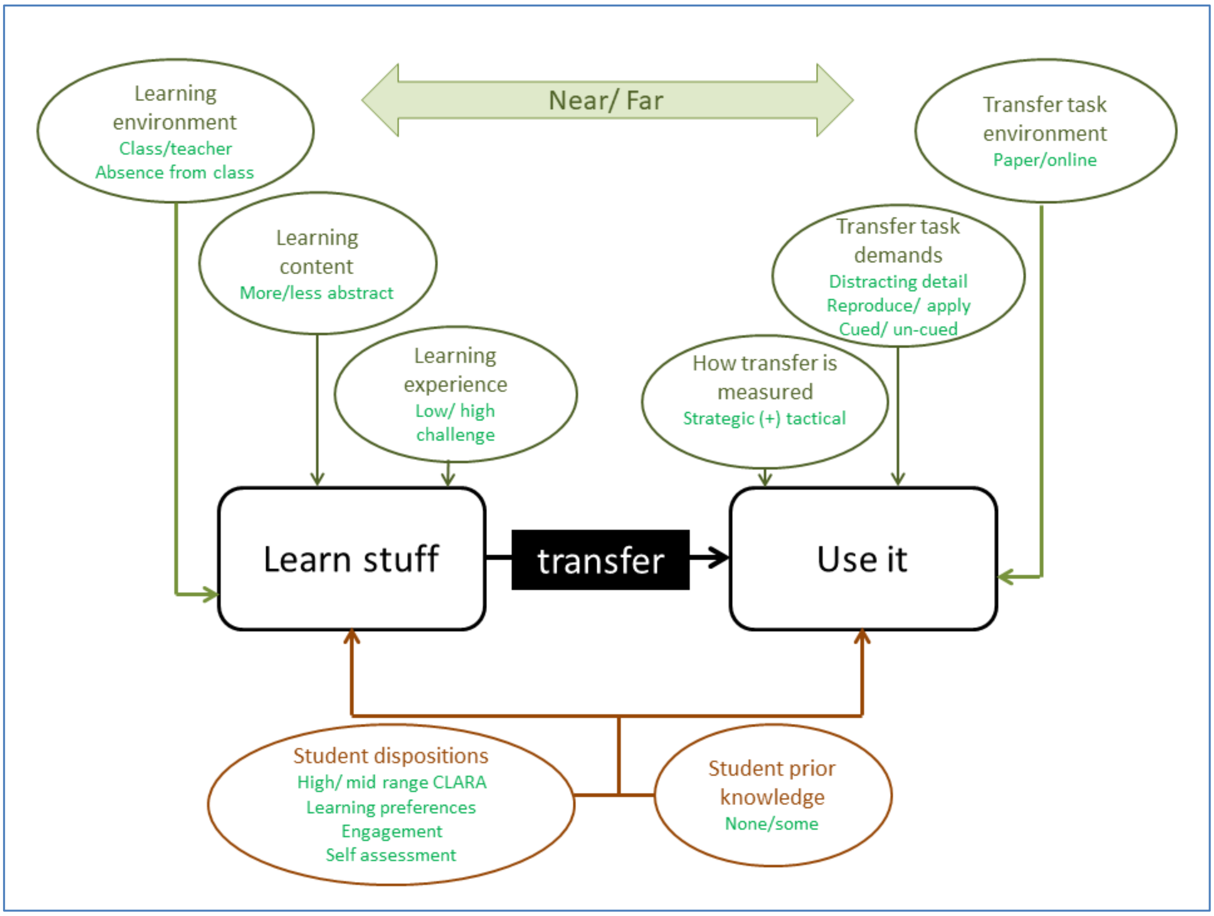
5.3.4 Discussion

This study has painted a detailed numerical picture of the transfer of two science curriculum concepts by 244 Year 6 students over two units of work. Rather than identifying a single factor that determines transfer, it points to a number of factors that may affect transfer through their interactions with each other and with the transfer process. The implications of these impacts for educators are discussed here.

5.3.4.1 Interconnectedness of factors affecting transfer

Chapter 3 outlined a framework describing factors affecting transfer of learning. This framework is reproduced in **Error! Reference source not found.** with the factors investigated in this field trial added.

Figure 5-26 Expanded framework for factors affecting transfer



The direct arrows give the impression of a simple relationship between each group of factors and the components of the transfer process. This study suggests that rather than a simple relationship between pedagogy and transfer, pedagogy has a differential impact on transfer depending on other factors. High challenge pedagogy had a slight positive effect on transfer under the following conditions:

- The concept is challenging for that group of learners (typically more abstract)
- Both strategic and functional transfer are called for (the learning is not cued)
- The transfer task has inherent difficulties, such as application rather than reproduction and distracting detail (especially emotive detail) in the context.

In addition, high challenge pedagogy may be particularly effective for:

- Learners with only average scores in dispositions of belonging, collaboration, hope and optimism and creativity
- Learners who express a preference for high challenge pedagogy

- Learners with less than full attendance

High challenge pedagogy was associated with a greater focus on the concept than the task.

This effect is hidden in many large scale studies. The meta-analysis of Stockard, Wood, Coughlin and Rasplica Khoury (2018) concluded that direct instruction was associated with better learning outcomes, while Cairns and Areepattamannil (2019), working with PISA data, reported that inquiry-based learning was associated with worse learning outcomes. Interestingly, both studies found better affective measures for inquiry-based learning. It takes deeper probing to investigate the differential effect of high challenge pedagogy on the group of learners described by Zvoch et al. (2021) as students "historically underserved by the education system".

Similar suggestions about the interconnectedness of motivation, classroom experience and student demographic features have been made by other researchers. Zvoch et al. (2021) found no significant difference overall between the achievement of students taught with direct instruction compared with guided inquiry, but when they took students' performance in the state maths test into account, low maths ability students did better in science taught by guided inquiry. Although the low SES group in the study of middle school science students by Bae and Lai (2020) does not necessarily correlate with the group of students with average CLARA scores, it still points to a differential impact of classroom strategies on student motivation.

5.3.4.2 Critical role of feedback in high challenge pedagogy

In this study, high challenge pedagogy was delivered by:

- Reversing the order of the explain and practical application tasks (5 E's explore before explain)
- Requiring a response from students to questions targeting the concept before explaining the science perspective
- Framing the concept as relevant for everyday life and future study rather than the topic of this science unit

Sessions were run from slides to minimise the differences between teachers. Explaining was done by videos that were identical in images and script except for the differences described above and similar in length. In response to the generally low transfer in the pilot study, feedback was incorporated in these units by students correcting their own responses from a slide, with one instance of peer assessment in activity 6. While improving the experimental design, the absence of teacher response targeting individual student thinking has probably decreased transfer for those students who did not self-assess critically. This decrease is less likely for the low challenge group whose task was to reproduce what they had been told and check they did it correctly than for the high challenge group. The task for the high challenge group who invoked their own thinking was more difficult, in that in many cases, they would have had to let go of their own ideas to adopt the idea presented. In their self-assessments, a greater proportion of the high challenge group (19% compared to 8% of the low challenge group) did not recognise when they were competent with the targeted concept. The low challenge group was more accurate in recognising their competence with the targeted concept but tended to overestimate this when there was no evidence.

Although there is a weak positive effect on transfer for high challenge pedagogy, the version of high challenge pedagogy implemented in this experiment may not do it justice. In this study, teacher feedback to students, which is considered important in learning (Wiliam, 2018, p. 1), was deliberately removed in the interest of consistency between teachers. Possibly, feedback is more critical with this pedagogy, which is consistent with the findings of Therrien, Taylor, Hosp, Kaldenberg and Gorsh (2011) that inquiry pedagogy is associated with better learning outcomes for low ability students when associated with feedback and behavioural support.

5.3.4.3 Relative time inefficiency of high challenge pedagogy

One disadvantage of high challenge pedagogy in the classroom is the time it takes for students to form an idea and then refine it in response to experience and feedback with other contexts. When teachers perceive curriculum as covering an extensive list of concepts and information, it is tempting to opt for tell and practice and move on. At least they can say that they have "covered" the material even if at least some students did not seem to learn it.

However, the cost of this becomes evident when the learning is measured by far transfer. There was some evidence in this study that learning acquired by low challenge pedagogy resulted in less transfer in more challenging tasks and faded more quickly with time.

5.3.4.4 Matching pedagogy to likely transfer scenarios

The interaction between high challenge pedagogy, the nature of the learning, and the transfer task suggests that no single pedagogy is the universal answer for all learning situations. If the goal is for learners to reproduce learning when called for, then tell and practice with feedback on how close students' attempts are to the desired outcome seems to be the most efficient way. While the educators, whose thinking is described in the introduction (Chapter 1), make the point that calls for this kind of transfer are decreasing with technological change, there are still both everyday and professional instances when this is necessary. The words of the national anthem, safety procedures and device operating procedures might fall into this category. However, if the goal is for more general concepts and principles that can be applied flexibly in a range of situations, including those we might not yet be aware of, then high challenge pedagogy with its emphasis on expansive framing and making the concept work in a context might be a more effective choice, especially for some learners. The nature and purpose of the learning influence the choice of optimal pedagogy.

5.3.4.5 Pedagogy and learner dispositions – a social justice issue

The interaction between pedagogy and learner dispositions suggests that not all pedagogies work equally well with all learners. Differences in transfer outcomes for each pedagogy are minimal for learners with high scores in many dispositions. The possible exception is the group of highly creative students who did better with tell and practice, maybe because this reined in their creativity and focused them on the target concept. In contrast, high challenge pedagogy gave students a license to use their creativity but penalised them if they did not eventually adopt the targeted concept.

However, for learners with lower creativity, high challenge pedagogy seems to have supported their engagement with the concept and their ability to apply it un-cued in and less familiar contexts. This effect was not limited to creativity. Students with only average scores in all CLARA dimensions but curiosity transferred better with high challenge pedagogy, most noticeably in belonging, collaboration and hope and optimism.

The link between learner dispositions and learning outcomes has been investigated for decades and was summarised relatively recently by Dweck and Yeager (2019). One solution to the gap in transfer between students with adaptive and less adaptive learning dispositions is to manipulate learner dispositions so that more students benefit from low challenge pedagogy. Success in this has been reported by Blackwell et al. (2007) and others, although a meta-analysis (Sisk, Burgoyne, Sun, Butler, & Macnamara, 2018) found only weak evidence for success in this from a range of studies. Selling growth mindset ideas to students has become accepted classroom practice in many South Australian schools, although the transfer from wall posters and growth mindset language to persistence and engagement in classroom tasks should not be taken for granted. I have been in classrooms in these areas where the walls are covered with student-made posters extolling the values of a growth mindset, yet there are tears, requests for help and emails from parents when students are asked a question to which they do not know the answer. Changing this culture requires working with the whole school community.

The alternative suggested by this study is for teacher pedagogy to best cater for the learners with mid-range dispositions. I have been in classrooms where disengaged, and disruptive students have become engaged and independent workers and even discussion leaders in response to high challenge pedagogies. However, adopting high challenge pedagogy may not necessarily be smooth sailing either. Although not appearing to disadvantage those scoring highly in learning dispositions, high challenge pedagogy is not necessarily welcomed by these learners. Many are competent in remembering and reproducing and have been successful with low challenge pedagogy for most of their schooling. The mental effort required to generate their own ideas and then refine them in the light of the scientific idea is considerably more and fraught with the possibility of making public mistakes. For some students, challenging this contests their beliefs about who they are as a learner (Wiliam, 2010).

5.3.4.6 Pedagogy to address the middle bands issue

The finding that high challenge pedagogy seems to be more effective with those with average learner dispositions while not disadvantaging those with higher learner dispositions, makes it a pedagogical approach that may better address social justice for learners. In national standardised testing, South Australia often differs from other states in having a higher percentage of students in the middle performing groups. While average performance does not necessarily correlate with average learner dispositions, wider use of high challenge pedagogy may assist some of these students to improve transfer, especially in more challenging tasks.

5.3.4.7 Learning trajectories and the role of experimentation and collaboration

The visual representation of student learning trajectories in one class (**Error! Reference source not ound.**) has similarities with a QR code in its apparent randomness. Many students dipped in and out of transfer of the targeted concept over the learning sequence. This variability could be accounted for by the features of the tasks themselves affecting the difficulty of transfer, by minimal teacher feedback leaving the way open for students to experiment with ideas or by collaboration between changing groups of peers. The takeaway messages for teachers are that there are many pathways to successful transfer and that the sharing of ideas, especially those inconsistent with the science concept, should not necessarily be discouraged. These so-called wrong ideas allow teachers to discuss the advantages and limitations of different ideas with the class as well as provide targeted feedback to individual students.

From a study investigating the development of student thinking about the structure of matter, Talanquer (2009) also concludes that there were many possible pathways to develop expertise. He identified four dimensions along which student thinking developed and noted that progressing along each of these pathways at different rates could explain the variability in ideas students demonstrated. In addition to progressing at different rates, the learning trajectories in this study show that movement was not necessarily always forwards as there was evidence that students experimented with different ideas from one task to the next.

5.3.4.8 Knowing your transfer capabilities

For the pre and post-test tasks transfer was measured as one of three groups:

- No evidence of the targeted concept
- Strategic only - limited evidence of the targeted concept (name, vague reference or misconception)
- Strategic plus functional - application of the targeted concept in the context

It is tempting to see these as a hierarchy: you go from nothing, through recognising what you need but not being able to apply it (strategic only transfer) to finally recognising what you need and applying it in the context (strategic and functional transfer). However, there is also a fourth group (functional only) where students do not recognise situations when a concept is useful but can apply it if cued to do so. This functional only transfer was demonstrated in the cued tasks.

These can be thought of as different aspects of expertise. Those who can deliver both strategic and functional transfer have expert-like knowledge and can use it independently. They see the need for and enact transfer of this knowledge, refining it as they do. As the amount of knowledge increases, increasing specialisation of skills and knowledge is required, and any single person is capable of only limited amounts of expert-like transfer. In addition to their areas of expertise, an individual may also be capable of strategic transfer across a wider range of areas. They may recognise situations when transferring particular knowledge is appropriate but need to delegate or seek assistance for its application. Again the more they do this and the more feedback they get, the better they will become at identifying affordances for strategic transfer. The important thing is that they know when they have the functional expertise to carry out the transfer and when they should delegate, seek advice or check their thinking. Where an individual has only functional knowledge, they are reliant on someone with strategic knowledge to trigger the transfer of this. Unless this happens from time to time, they are in danger of forgetting the knowledge as they cannot initiate application on their own.

All of us fall into each of these groups at some time. All of us are capable of strategic and functional transfer in some situations and limited to strategic or functional in others. The latter two are not necessarily maladaptive, although there is an argument that the call for functional only transfer is decreasing with the move from an industrial to a technological society.

5.3.5 Experimental limitations

The constraints on conducting this experiment included:

- The need to minimise variation from extraneous factors to limit the number of variables that could affect outcomes;
- The need to carry out the experiment under conditions as close as possible to students' regular school experience to make the findings relevant to classroom teachers;
- Limits on the number of participants that the researcher could manage in the classroom delivery and data collection phases; and
- The need to minimise harm, burden or inconvenience for the teacher and student participants.

At times, these constraining forces pulled in opposing directions, and the compromise will have affected the experiment's outcomes. Some of these are discussed here.

5.3.5.1 Factors limiting sample size

- ***Expressions of interest from schools***. Emails advertising the project were sent to principals of 30 primary schools to be forwarded to classroom teachers of years 5, 6 and 7. Eight schools responded, and five agreed to participate, one of which later withdrew from the project. The four remaining teacher participants were specialist science teachers rather than classroom teachers, although one of these passed the project on to classroom teachers.
- ***Cost and access to CLARA learner dispositions survey***. Even though the considerable cost of student participation in the CLARA survey was met by the centre for Science Learning in the 21^{st}-Century at Flinders University, accessing the survey still proved challenging for many students. Students had to remember log-in details (email addresses and passwords) and have access to an internet-enabled device at a convenient time. Not one of the 80 students from school A completed it, and others had patchy participation rates. Overall, there was CLARA data for 131 out of the 244 students, effectively halving the sample set for any analysis involving student dispositions.
- ***Return of consent forms***. Ethics approval required student participants to opt-in by returning a consent form signed by their parents. Teachers reported that getting any form returned can be a challenge, even for events that students are keen to participate in. Some teachers were active in encouraging and reminding students to do this, while others left it more up to

students so that some classes had almost full participation and others around half. Given that the two units were required class work for all students, whether or not they returned a consent form, it would be better to go with an opt-out consent form as with many other school programs.

- ***Student absence from class***. Overall the four participating schools had an attendance rate of greater than 95%, but when absences from class for in-school programs were taken into account, the attendance rate for both the pre-test and post-test tasks was 86% for Unit 1 and 84% for Unit 2, reducing the sample size from 244 to 211 and 206 respectively.
- ***Researcher management of research phase and data collection phase***. Managing the program in the four schools proved complex as they began at different times and progressed at different rates. In addition, they generated about 7000 written responses to tasks and surveys, which needed to be analysed for evidence of transfer. The time needed to do this was limited the number of participants that could be included in the research study.

5.3.5.2 Factors affecting the implementation of the classroom program

- ***Factors associated with teachers***. Students' regular teachers delivered the learning programs to make the learning situation as close as possible to regular classrooms. The researcher met with teachers before each unit and at regular intervals to clarify their role in delivering the program. Some teachers went out of their way to sell the idea of participating in research to students. However, over the study, there were changes in teachers, either relief teachers when the regular teacher was absent or replacement teachers when the original teacher moved to a different role. Teachers indicated that the replacement teachers had been briefed on the research project, but even though the learning materials included slides, lesson plans and suggested questioning, some teachers may have been less faithful to the procedures than others.
- ***Factors associated with students***. The disposition and engagement of students were measured as part of the variables in the study, but another limiting factor was students' capacity to record their thinking in written form. Even though this requirement was about a paragraph for each task and should have been well within the capabilities of most students in year 6, requests for less written work was a recurring theme in the feedback sections. For the relatively high number of students for whom English was a second language, this written recording may have been more challenging and when coding evidence of transfer, attention was paid to distinguishing transfer of the targeted science concept from the literacy skills involved in constructing the response.

5.3.5.3 Factors associated with data collection

- ***Factors associated with the measurement of transfer from work samples.*** A single rater (the researcher) assessed evidence of transfer, removing inter-rater variation. To minimise the rater's bias, work samples were identified only by a code, and multiple passes were made. The procedure was to physically sort the papers into piles of responses belonging to a particular category and then revisit the responses in each category to check for consistency. These two steps were repeated at least four times until revisiting each pile of papers resulted in none needing to be moved to another category. This process is similar to how some teachers regularly assess classroom work, knowing that students would compare feedback and challenge any perceived inconsistencies. In addition, the initial categories were quite narrow, with relatively small numbers of samples in each. After the grading, they were combined into fewer, broader categories with more samples in each, so that discrepancies in grading would have disappeared in the amalgamation.
- ***Factors associated with measuring learning dispositions and preferences.*** In addition to the factors associated with accessing the CLARA dispositions survey, there may have been issues related to the literacy demands and persistence required to complete it. The creators of CLARA claimed that it had been successfully verified with students of the same age as these participants. Student and teacher feedback from those students, who did complete it, was that it was a test of stamina to get to the end, but that students took it seriously. Although students' responses were available for the school to use to develop their students' learning capacity, no schools took up this offer.

5.3.5.4 Other sources of error

- With the opt-in requirement for consent, it is possible that students returning permission slips may not have been a representative sample of the school. While this might affect the generalisability to other schools, there would be no expected difference between the matched classes in each school.

- Work samples were misplaced and redone at another stage in learning for two tasks in Unit 1 for both matched classes in one school. This means that compared with other schools, these students had extra tasks and two weeks of holidays in between completing the work samples, and this may have affected transfer.

- For one class (D3), a relieving teacher, who had minimal instruction in the research, delivered some lessons. The teacher instructed students not to name work, and two-thirds of the class had to recognise their work samples several weeks after producing them. This was not one of the matched classes, and their results for Unit 2 were not included in the sample.

- At times too much help may have been given to the productive struggle students. High challenge pedagogy is not familiar to many teachers and students, and the combination of students being uncomfortable with the struggle and teachers seeing it as their job to help and set up success may have resulted in prompting or scaffolding before students have had a go.
- Unnamed work samples may have been attributed to the wrong student. When work samples were un-named, elimination from the class list and handwriting matching were used to attempt to identify them. If this could not be done confidently, the work samples were removed from the data set.
- Mistakes may have been made in entering codes onto the spreadsheet. To minimise keyboard entry errors, each code was checked after entry, and most codes resulting from a typing error would not have made sense and would be detected when summing data.
- Despite every effort to keep the research activities as close as possible to the regular classroom program, student responses may have been influenced by the students' awareness that they would be examined for research. It is possible that some students were telling a story they thought I wanted (or didn't want) to hear. This may have been more likely at the beginning when they were aware of the research because of the paperwork required, but less likely as the project ran its term for at least 24 weeks. The work samples produced seemed little different to what I have collected from classes I have taught.

5.3.6 Conclusion

This research was conducted with a quasi-experimental design in the complex settings that are school classrooms. While every effort was made to minimise control extraneous variables and ensure that the research process was implemented faithfully, the messiness of school life will inevitably have affected the transfer assessed in unforeseen ways. Rather than producing a definitive road map to ensure the desired outcome of transfer of learning, the findings of this study describe a landscape in which transfer occurred and suggest interactions between some of the features of this landscape that may have affected transfer. There is greater clarity around what is not part of the landscape than what is. There is no single way to measure transfer, no single recipe for a program to deliver transfer and no single outcome of any one combination of program and measure of transfer. The often overlooked part of the landscape is the role of the learners. It would be difficult for a single teacher of a class of 30 students to manage the complexity of the interactions between the factors without enlisting the help of the students themselves as they each have insight into their own perspective on these factors. Further study could look at what happens when students' perspective is considered in planning and delivering learning experiences.

6 General Discussion

This thesis has investigated the impact on transfer of learning of three groups of factors – those associated with the learning of the concept, those associated with the transfer situation, and those associated with the students themselves. In addition to identifying and categorising factors, the research sought information on their effects. The studies in Chapter 5 outlined a web of interconnected factors, and because of interactions between these factors, the answer to how any single factor affects transfer is: *It depends on ….*

In the T1 and T2 scheme for translational research described by Woolf (2008), the research described in this thesis aligns with the T1 phase in that it sought to identify research findings (largely from laboratory studies) on transfer of learning with general classroom potential, use them to construct materials for use by educational practitioners in classrooms and evaluate effects of their use in classroom situations. The T2 phase of translational research is the dissemination of research findings back to the community involved, and one audience for this dissemination is classroom teachers. However, while factors related to the learning environment and the learning experience lie within the sphere of influence of classroom teachers, major influences on some of the other factors come from other members of the education community. For example, the concepts to be learnt are determined by national curriculum writers, while the transfer tasks are variously determined by assessment authorities and individual or teams of teachers and possibly site leaders. The way transfer is measured is strongly influenced by state government policymakers who produce guidelines for assessing and reporting student work. In addition, the students themselves have influence on and understanding of their own dispositions and prior knowledge. These spheres of influence overlap. Over the time they have with each class, teachers can influence the dispositions of their students, and on a longer time frame, their feedback may influence the documents constructed by policymakers and leaders. Feedback from students may influence the learning activities provided by their teachers. This chapter considers the implications of this research for each of these groups of stakeholders.

6.1 Implications for classroom teachers

What works? is a common catchphrase among educators seeking ideas from research findings to improve their effectiveness. Hattie (2009) expanded this idea to become, *How well does it work*? by introducing effect sizes to the communication of research findings to practitioners. Farmer (2020) has gone a step further by suggesting a more nuanced approach with a tiered system becoming more like *What works, when and for whom?* so that research findings are applied to the appropriate subgroups of students with particular learning needs. He distinguishes interventions that work for most students from those that work for selected students, and finally, those that work for targeted students. It then falls to teachers to identify and deliver strategies appropriate to the learning needs of students in their class at any particular time, no mean feat given the diversity they can expect to have amongst the 30 students for whom they are responsible. I am mindful of the complexity of teachers' roles and the associated workload in offering the following suggestions.

6.1.1 Clarity around the intended learning and the situations in which transfer of the concepts is sought

Specialist and general classroom teachers in South Australian Primary Schools have responsibility for up to eight year levels (Reception to Year 7 at the time of this study) or up to eight curriculum areas (the Australian Curriculum has eight required learning areas)respectively, and a thorough understanding of the range of concepts involved takes time to acquire. The effort involved may pay dividends in improving students' capacity to transfer by acting at two stages in the learning sequence. A thorough understanding of both strategic and functional aspects of curriculum concepts enables teachers to evaluate existing tasks and design new tasks targeting the intended science concept. In the formative assessment stage, teachers with a good understanding of the intended learning would be better placed to assess student understanding of the targeted concept from evidence in work samples and discussions and formulate feedback targeted to the understanding demonstrated.

In addition to clarity of the intended learning, teachers who have clarity around the situations in which students might usefully transfer the targeted concepts should be better placed to select the most efficient pedagogy for the situation and work with students to develop the strategic aspects of the targeted science concept. Including a range of far transfer experiences in the learning program will allow students to practice using the concept in a range of contexts which should better support fat transfer.

6.1.2 Student learning dispositions and pedagogy

There is evidence that in the experiment reported in chapter 5.3, that high challenge pedagogy catered better for students with mid-range learning disposition scores while not disadvantaging those with higher scores, and therefore it offers a potential tool for improving transfer of students in the middle bands. However, moving to high challenge pedagogy may not be smooth sailing, and resistance could be expected from some students with more adaptive learning dispositions, whose current comfort level is challenged by high challenge pedagogy. This resistance may take persistence and explanation to overcome.

Some CLARA[19] learning dispositions such as mindful agency, sense-making, curiosity and creativity measure in part the degree to which students play an active role in their learning rather than being passive recipients of ideas. Fostering a sense of driving their learning might result in more adaptive CLARA learning dispositions, which may help students benefit from high challenge pedagogy by valuing their thinking. These dispositions would need to be developed by providing opportunities, expectations and coaching in the learning process in addition to the usual classroom focus on curriculum concepts. The benefits of students taking a more active role in their learning may extend beyond the current science unit of learning to other learning areas and future learning situations.

The impact of student learning dispositions is not limited to individual students but includes interactions between students, not directly measured by the learning surveys. Class culture is difficult to predict from a list of student names and individual data, but it can be powerful in supporting or limiting learning for class members. The teacher respondents to the class culture survey in Chapter 5.3.3.2.5 described prevailing attitudes to learning and behaviour in the class, often attributing them to the behaviour of a few students. Attempting to change class culture to improve behavioural engagement can take considerable time and energy on behalf of the teachers. High challenge pedagogy may assist, particularly in the case of challenging classes.

6.1.3 Feedback

The importance of feedback in improving students' learning has recently received considerable attention in South Australian schools. It was the major focus of the three-year strategic development plan for DECD in 2017 (Department for Education and Child Development, 2017a). Strategies and rationale put forward by Dylan Wiliam (Wiliam, 2018) have been disseminated widely among teachers. With low challenge pedagogy, feedback rewards successive approximations of the transfer sought. The results of experiment 5.2 suggest that with high challenge pedagogy, where the implicit license to think allows students to generate a range of ideas, feedback is also important to help them identify what, from these ideas, is and is not relevant to the targeted science concept. Feedback needs to support understanding of both strategic and functional aspects of the concept.

[19] https://utscic.edu.au/tools/clara/

6.2 Implications for educational administrators, policymakers, curriculum developers and assessment writers

As they operate at a system rather than classroom level, the sphere of influence of educational policymakers, curriculum developers and administrators lies in their description of the learning to be transferred, and their selection of the high stakes transfer situations. Their work can deliver the clarity described above by aligning the targeted learning described in the curriculum and the assessment practices valued. If the curriculum asks for high-level transferrable concepts but assesses the reproduction of details, then lower rates of transfer could be expected than if the curriculum and the valued assessment are aligned. Likewise, a curriculum specifying a list of expected knowledge and assessing transfer of the underlying concepts to new contexts is also likely to result in sub-optimal transfer.

Both 21st-century learning and STEM have outcomes involving far transfer - the transfer of concepts into new and as yet unforeseen circumstances (Department for Education and Child Development, 2016, p. 1). To support this kind of transfer, policy and practice should include assessments with a smaller number of tasks involving transfer of high-level concepts into new contexts in addition to the usual format of many tasks covering a range of concepts. Although extended response tasks are more complex and expensive to assess, they can give complementary indications of thinking for students from a range of backgrounds. The associated literacy issues will differ, with reading skills affecting transfer in multiple-choice questions, while extended response tasks require writing skills. This change might require a change of thinking for the designers of large scale assessments. Crisp, Johnson and Constantinou (2018) studied seven examination question writers and found that while they all considered that questions should allow students to show understanding at a range of levels, only one of the seven considered that requiring more than recall and understanding to be an indicator of quality in test question writing. This finding of Crisp et al. (2018) suggests that there is some work to be done not only in skilling question writers in developing this type of question but also in valuing questions that demand far transfer.

Finally, those who deliver professional development to teachers should consider the points for teachers if they are seeking transfer of the ideas presented in professional development sessions to classroom practice. While there is considerable work on transfer of skills in workplace settings, recommendations from this work are often overlooked when delivering professional development for teachers. The results of the experiment reported in chapter 5.3 showed that disseminating information does not automatically lead to the desired changes in classroom practice, just as telling students about transfer of electrical energy does not always result in them using ideas they have been told to explain how a circuit works. The know-do gap described by Mitchell (2016) illustrates the importance of considering teachers' perspectives if professional development is to have the desired impact.

6.3 Implications for students

Figure 6-1 Transfer for learners – a set of questions for students to promote self-efficacy with transfer.

Transfer for learners

So there's a new idea … here are some questions to think about:

Seek to understand when, where and why, as well as what and how about new ideas

- What is it for? When and where is it used? Where else? Where else? What's the same about these? When is it not used? Why not? What does it do? If this idea didn't exist, how would things be different?
- How does it work? What information do you need to find? What do you do with this?

Use others' ideas to help and not just experts.

- What do other people think? Can you see why they might think that? Does it make sense to you? Can you explain why you see it differently? What does someone who knows about this say about your ideas?

Be prepared to update your thinking – again and again

- How do I know this? Does everyone agree? What might people have thought before this?
- How do you think differently now compared to last …

Make connections

- How does this connect with other things you know? What else is like this? What might someone else see if they looked at this?

The first message in the questions in **Error! Reference source not found.**is about actively engaging ith learning. Even the most skilful and motivated classroom teachers cannot engage with and respond to all individual learners all the time, so students who take the opportunity to drive their own learning will benefit more from the learning opportunities offered at school. In addition, they will be better set up to make the most of any less than ideal pedagogy they will undoubtedly encounter somewhere in their lifelong learning future.

The second message is about far transfer. Increasingly near transfer, simply being able to reproduce something when cued, is of less value than being able to draw on a range of possibilities when producing a response to a situation. High challenge pedagogy offers a pathway to far transfer for a range of students. The high challenge students who had had the opportunity to think about the strategic aspects of concepts did better in the far transfer post-test tasks in the experiments described in Chapters 5.2 and 5.3.

Another message is about positioning learning as an ongoing series of iterations of changing your mind. This perspective seeks to turn potential damage from unsuccessful transfer into steps in an ongoing progression that can be as rich as the learner chooses. Rather than the message of: *I'm not good at … because I failed*, learning positioned as ongoing changing you mind is associated with thoughts like: *well, that didn't work, so what can I change? I haven't got that yet.* The current learning experience is positioned on a continuum (or more accurately, a web of interconnected continua) of lifelong learning, acknowledging that progress along this continuum will be variable in speed, sometimes rapid, sometimes apparently stalled or even backwards. This view of learning contrasts with a model of school learning as a gradual acquisition of a collection of knowledge pieces, disconnected in time and from each other.

Finally, the message is about using peers as resources for your learning rather than competition or interference. Except for privately tutored or homeschooled students, learning comes with a group of peers, with varying degrees of similarity to and differences from each other. While classes with high diversity are often seen as a challenge for teachers and a learning disadvantage for students, using the diverse perspectives brought by different students in these classes has the potential to enhance transfer by providing diverse contexts and diverse instances of successful and unsuccessful transfer.

6.4 Implications for educational researchers

6.4.1 Targeted and expanded perspectives on transfer

Although the increasing adoption by researchers of the situated perspective on transfer has addressed some of the debate on transfer as a construct, it is worth acknowledging that transfer is multifaceted and, at least for educators, both the targeted perspective and the expanded perspective have application for which the other does not suffice. In translational research, there can be a continual interplay between these two perspectives as each informs the research on the other.

6.4.2 Disseminating/ communicating research findings

Data from real classrooms is an asset in encouraging change-sceptical educators to translate research findings into classroom practice. Methods from translational research show teachers that the ideas can be practically applied in classroom settings like theirs. Findings from translational research give them confidence that the effort required may pay dividends in better learning outcomes for their students and the evidence to reply to challenges about pedagogy from other members of the school community. Both the classroom materials and results of the experiments reported in chapter 5 have been used in teacher professional development.

Researchers aiming for impact on an industry (i.e. school-based) audience should consider the points for teachers if they seek transfer of research findings to industry contexts.

6.4.3 Challenges of translational research

Mitchell (2016) points out that education is a relatively new domain for translational research and entails particular challenges. She identified four challenges in particular, which are discussed in the context of this study below.

6.4.3.1 Oversimplification

Translating dependent and independent variables from laboratory research into classroom learning programs requires a compromise between preserving the key aspects of the research findings while still producing a workable classroom program. When the intervention targets teachers and relies on their transfer of the key aspects into classroom practice, it runs the risk that, like transfer in the students they teach, only part of the desired strategy is implemented, or other variables persisting from their original practice counteract the targeted variables. For instance, teachers upskilled in productive struggle may still decide to maximise student success in a lesson by running a warm-up task that prompts or scaffolds the learning, interfering with the opportunity for students to use strategic thinking about the concept.

By providing a detailed program for teachers to implement, this study sought to minimise differences in pedagogy between teachers and maximise their adherence to the targeted pedagogies. Learning activities were run from a slide show, explaining was done by video, and the lesson notes included suggested questions or phrases to use at each stage. In addition, the rationale for each pedagogy was explained and reinforced to the teachers involved. What cannot be guaranteed is how faithfully teachers (especially relief and replacement teachers) adhered to the program, and it is certainly possible that some breaches of the set program have affected transfer.

6.4.3.2 Ethics

Like the health sciences, translational research in education involves human subjects, and Mitchell raises concerns about methodology, informed consent and privacy. The individual studies in Chapter 5 detail the care taken with the research methods so that as closely as possible, they mirrored students' regular classroom experiences, and there was no difference in treatment between those students who did and did not take part in the research. Because of the age of students, informed consent was required from parents and assent from students. Within the legal requirements of the university, every effort was made to use plain English on the associated forms and the implications of participation were explained by the teacher and researcher. After work samples had been matched to students, schools, teachers and students were identified only by alphanumeric codes and most of the data published is aggregated. It is possible that some of the teachers involved might recognise their school from the demographic details, and this risk was detailed in the consent form.

The other ethical issue relevant to translational research is participant input and critical evaluation into the research process. Both teacher and student participants were asked regularly for their feedback on the learning activities, and this feedback was used to interpret the results. Some feedback from Unit 1 of the field trial informed the tasks developed for Unit 2. Preliminary findings for the pilot study in Chapter 5.2 were shared with the teacher involved. The same offer of sharing was made to all participants in the field trial (Chapter 5.3) and taken up by one of the three schools. Seeking participant input and evaluation treads a fine line between validating study findings and adding extra burden to participants.

6.4.3.3 Skills and collaboration

The researcher in this project had a background of extensive classroom teaching experience in primary schools and research experience in science and drew on both of these to conduct the study. Similar studies could also be carried out by partnerships between researchers and classroom practitioners, with the added benefit of upskilling each in the expertise of the other. The involvement of classroom teachers in planning, implementation and communication might give the findings extra credibility amongst their peers.

Given the already high workload of classroom practitioners, their participation as collaborators in translational research projects would need to be supported if not to put an untenably high burden on them. One option is to release teachers from class, which can be expensive and interfere with the continuity of the learning program for students. Another option is for their participation in translational research to count towards mandated professional development requirements.

6.4.3.4 *Further research*

The findings of the experiments are limited to the small data sets provided by the 6 South Australian primary schools involved. As well as verifying these findings in other school contexts, some gaps in this research could be followed up.

- There was very little data on the effect of pedagogy on transfer for learners who scored in the lower range of CLARA learning dispositions, and more research needs to be done to investigate the effect of pedagogy on transfer for this group. It is possible that high challenge pedagogy also works well for this group and also possible that other modifications might be needed to enhance it for these learners. This research would involve working schools with a different demographic and may have extra challenges around informed consent and absence from class.
- A connection between pedagogy and engagement dimensions of learners was suggested by inferring engagement from feedback given. A qualitative study might offer extra information on how high challenge pedagogy works for different learners and what makes it successful with one group and unsuccessful with another. Understanding the different responses to high challenge pedagogy might help fine-tune the pedagogy to cater for a wider group of students.
- There is further work to do in disseminating these findings to teachers, was not investigated in this project. My personal experience as a learning leader across five schools indicates that successful incorporation of high challenge pedagogy into teachers' classroom repertoire is enhanced by time to implement cycles of plan, implement and debrief; support and expectations from leadership; and collaboration with peers in the planning and evaluation stages. Collaborative projects between researchers and partnerships of schools, in which the language of transfer was front and centre, could further investigate how teachers might best prepare all students in their class for transfer in a 21st-century future.

Glossary

Affordances are opportunities provided by a task for applying particular concepts. Task contexts may offer affordances for several different concepts as well as that targeted by the task developer and students may engage with these at the expense of the targeted concept.
Bounded framing positions the learning content as the topic of the learning for this time period and necessary for success in this class.
Causal net – see coordination class
Constructivist –. refers to a learning theory and related pedagogy where learners are considered to construct their own knowledge from their experiences
Coordination class is a framework used by researchers to describe the separate pieces of a concept and how they work together. Core function, span and alignment, readout and causal net are parts of a coordination class. ***Core function*** of a concept refers why it exists or what can be achieved by using it. ***Causal net*** refers to the set of rules, patterns or relationships associated with the concept that define how it works. ***Span and alignment*** refer to the range of situations where a context can be applied and the similarities between them that ensures the concept is used consistently ***Readout*** refers to the aspects of a task context that need to be identified before the causal net can be applied
Core function – see coordination class
Cuing in a task occurs when the context or the prompt indicate which concept would be useful in producing a response. This can range from a direct instruction e.g. *Use tectonic plates to explain …* to a suggestion as when the words *tectonic plates* appear in the context.
Evidence of transfer is provided by student responses to the task. Without direct access to a student's brain it is not possible to view the process of activating an applying learning and thus we have to infer this from their response. For classroom teachers this can include oral responses and

body language, but for this research written work samples like those transcribed in were the only sources of evidence available. The content and sophistication of the transfer was inferred from these.
Expansive framing positions the learning content in terms of its application to the real world or connection to other learning now or in the future.
Far transfer – see near transfer
Framing refers to the reasons given as to why students should engage with the learning content or how the learning is positioned in relation to students' lives. Bounded and expansive framing are contrasting framing used in this research.
Goals refer to the goal structures that underpin students' participation in classroom activities. The two extreme positions are: ***Mastery goals***, which are characterised by an orientation towards better learning ***Performance goals***, which are characterised by an orientation towards good performance.[20]
Grounded transfer is the range of prior conceptions that learners activate and apply in a situation.
Learning, used as a verb, refers to the act of acquiring those mental resources.
Learning, used as a noun, refers to collection of mental resources that a student has acquired both as part of their schooling and their life outside school. This includes but is not limited to concepts described in the mandated curriculum. The latter are described by the coordination class framework later in this section.
Limited conceptions refer to thinking which is only partially consistent with western science. Usually it does not go far enough in explaining or describing the targeted concept.
Misconceptions here refer to thinking which is not consistent with western science. In other works these may be referred to as alternative conceptions or naïve knowledge.
Multiple contexts refers to the practice of offering students examples or opportunities to engage

[20] Kaplan, A., Gheen, M., & Midgley, C. (2002, Jun). Classroom goal structure and student disruptive behaviour. *Br J Educ Psychol, 72*(Pt 2), 191-211.

with a concept in a wide range of situations and examples. The opposite is where the learning is restricted to one situation, possibly in greater depth.
Near transfer refers to transfer in a situation which is similar to the situation in which the concepts were learnt. Similarity may be measured in one or more of 6 dimensions; learning area, time, place, function, mode or social conditions.[21] The opposite is far transfer, in which the learning and transfer situations differ in one or more of these dimensions. The scale is comparative rather than absolute. It is possible to suggest that one particular situation is nearer than another, but not to assign a value of "nearness".
Pedagogy refers to the actions of teachers in delivering learning activities for their students. Tell and practice and productive struggle are different pedagogies used in this research.
Productive struggle refers to a pedagogy in which students are challenged to engage with a task using their existing mental resources before they are provided with the information necessary to complete the task. They do not have to struggle until they are successful, just until they have identified a gap in their mental resources.
Readout see coordination class
Solution path – see task
Span and alignment – see coordination class
Standardised test – an individual assessment practice which compares student results to those of a large cohort of students. Those mentioned in this thesis are: NAPLAN – National Assessment Program Literacy and Numeracy[i22] NAP-SL – National Assessment Program Science Literacy[23] PAT Science – Progressive Achievement Tests - Science[24] TIMSS – Trends in International maths and Science Study[25] PISA – Program for International Student Assessment[26]

[21] According to Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin, 128*(4), 612-637.
[22] https://www.nap.edu.au/
[23] https://www.nap.edu.au/nap-sample-assessments/science-literacy
[24] https://shop.acer.edu.au/progressive-achievement-tests-in-science-pat-science.html
[25] https://www.acer.org/au/timss

Students, learners and ***participants***. Because this research has been carried out in classrooms, the people whose transfer is being investigated are referred to as ***students***. The term ***learners*** has been used where it refers to literature from researchers who use this term. The term ***participant*** has been used when describing experimental method.
Task context – see task
Task environment refers to a whole range of social and environmental aspects of the circumstances in which a task is carried out. The term ***context*** has been used quite variably by transfer researchers. In some cases it is synonymous with the task environment, but it could also relate to the students or learning area of the research e.g. this research is done in the context of science learning by upper primary students. In this study context refers to task context as described above.
Task is an activity that students are asked to do to engage with the learning. A task has three parts: context, prompt and solution path. ***Task context*** is the setting of the task. This may be presented by verbal descriptions, images, concrete materials or any combinations of these. ***Task prompt*** which sets out the response required of students ***Task solution path*** is the process that a student goes through to generate the response (Nokes-Malach & Mestre, 2013)
Task prompt – see task
Task solution path – see task
Tell and practice refers to a pedagogy in which students are provided with the information necessary to complete the task before they attempt the task. They may also be scaffolded to complete the task.
Targeted transfer is the activation and adaptive application of curriculum concepts in non-rehearsed situations.

[26] https://www.oecd.org/pisa/

Bibliography

Abercrombie, S. (2013). Transfer effects of adding seductive details to case-based instruction. *Contemporary Educational Psychology, 38*(2), 149-157. https://doi.org/http://dx.doi.org/10.1016/j.cedpsych.2013.01.002

Abercrombie, S., Hushman, C. J., & Carbonneau, K. J. (2019). The impact of seductive details and signaling on analogical transfer. *Applied Cognitive Psychology, 33*(1), 38-47. https://doi.org/10.1002/acp.3475

ACARA. (2021a). *Australian curriculum*. ACARA. https://www.australiancurriculum.edu.au/about-the-australian-curriculum/

ACARA. (2021b). *National assessment program*. Australian Curriculum, Assessment and Reporting Authority. https://www.nap.edu.au/

ACER. (2013). *Tests of reading comprehension teacher manual*.Melbourne, Australia: Australian Council for Educational Research.

Alexander, P. A., & Murphy, P. K. (1999). Nurturing the seeds of transfer: a domain-specific perspective. *International Journal of Educational Research, 31*(7), 561-576. https://doi.org/http://dx.doi.org/10.1016/S0883-0355(99)00024-5

Anderson, G. L., Krathwohl, D.R., Airasian, P.W., Cruikshank, K.A., Mayer, R.E., Printich, P.R. et als (Eds). (2001). *A taxonomy for learning, teaching and assessing: a revision of Bloom's taxonomy of educationla objectives.*Boston: Allyn & Bacon.

Anderson, J. R., Reder, L. M., & Simon, H. A. (1996). Situated learning and education. *Educational Researcher, 25*(4), 5-11. https://doi.org/10.3102/0013189x025004005

Anderson, R. J., Dewhurst, S., A, & Nash, R., A. (2012). Shared cognitive processes underlying past and future thinking: the impact of imagery and concurrent task demands on event specificity. *Journal of Experimental Psychology, 38*(2), 356-365.

Antonietti, A., & Gioletta, M. A. (1995). Individual differences in analogical problem solving. *Personality and Individual Differences, 18*(5), 611-619. https://doi.org/http://dx.doi.org/10.1016/0191-8869(94)00187-W

Australia drops in PISA rankings: Should we be worried? (2019, 07 12 2019). *Education Matters*. https://www.educationmattersmag.com.au/australia-drop-in-pisa-rankings-should-we-worried/

Australian Academy of Science. (2012). *Primary connections: Linking science with literacy*. Australian Academy of Science. Retrieved 25 November 2021 from https://primaryconnections.org.au/

Australian Broadcasting Commission. (2014). *NAPLAN results show South Australian students behind national average*. Australian Broadcasting Commission. Retrieved January 31, 2022 from https://www.abc.net.au/news/2014-08-18/naplan-results-show-sa-students-behind-national-average/5677286

(2017). *Australian Curriculum* http://www.australiancurriculum.edu.au/Curriculum/Overview

Bae, C., & Lai, M. (2020). Opportunities to participate in science learning and student engagement: A mixed methods approach to examining person and context factors. *J Educ Psychol, 112*(6), 1128-1153. https://doi.org/10.1037/edu0000410

Baker, D. L., Basaraba, D. L., Smolkowski, K., Conry, J., Hautala, J., Richardson, U., English, S., & Cole, R. (2017). Exploring the cross-linguistic transfer of reading skills in Spanish to English in the context of a computer adaptive reading intervention. *Bilingual Research Journal, 40*(2), 222-239. https://doi.org/10.1080/15235882.2017.1309719

Bardach, L., Oczlon, S., Pietschnig, J., & Luftenegger, M. (2020). Has achievement goal theory been right? A meta-analysis of the relation between goal structures and personal achievement goals. *J Educ Psychol, 112*(6), 1197-1220. https://doi.org/10.1037/edu0000419

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin, 128*(4), 612-637.

Barron, K. E., & Harackiewicz, J. M. (2001). Achievement goals and optimal motivation: Testing multiple goal models. *Journal of Personality & Social Psychology., 80*(5), 706-722.

Barron, K. E., & Harackiewicz, J. M. (2003). Revisiting the benefits of performance-approach goals in the college classroom: exploring the role of goals in advanced college courses. *International Journal of Educational Research, 39*(4–5), 357-374. https://doi.org/http://dx.doi.org/10.1016/j.ijer.2004.06.004

Barth-Cohen, L. A., & Wittmann, M. C. (2017). Aligning coordination class theory with a new context: Applying a theory of individual learning to group learning. *Science Education, 101*(2), 333-363. https://doi.org/10.1002/sce.21264

Bassok, M., & Holyoak, K. J. (1989). Interdomain transfer between isomorphic topics in algebra and physics. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 15*(1), 153-166.

Beach, K. (1999). Consequential transitions: A sociocultural expedition beyond transfer in education. In *Review of Research in Education* (Vol. 24, pp. 101-139). https://doi.org/10.3102/0091732x024001101

Beck, J. W., & Schmidt, A. M. (2013). State-level goal orientations as mediators of the relationship between time pressure and performance: A longitudinal study. *Journal of Applied Psychology, 98*(2), 354-363.

Beker, K., Kim, J., Van Boekel, M., van den Broek, P., & Kendeou, P. (2019). Refutation texts enhance spontaneous transfer of knowledge. *Contemporary Educational Psychology, 56*, 67-78. https://doi.org/https://doi.org/10.1016/j.cedpsych.2018.11.004

Bell, B. (2005). *Learning in science The Waikato research*.Oxford, United Kingdom: Routledge-Falmer Taylor Francis Group.

Belland, B. R., Kim, C., & Hannafin, M. J. (2013). A framework for designing scaffolds that improve motivation and cognition. *Educational Psychologist, 48*(4), 243-270. https://doi.org/10.1080/00461520.2013.838920

Benander, R. (2018). *A literature summary for research on transfer of learning* (Future of Education and Skills 2030: Conceptual Learning Framework, Issue. O.E.C.D.

Bereby-Meyer, Y., Moran, S., & Unger-Aviram, E. (2004). When performance goals deter performance: Transfer of skills in integrative negotiations. *Organizational Behavior and Human Decision Processes, 93*(2), 142-154. https://doi.org/http://dx.doi.org/10.1016/j.obhdp.2003.11.001

Bernacki, M., Nokes-Malach, T., Richey, J. E., & Belenky, D. M. (2016). Science diaries: a brief writing intervention to improve motivation to learn science. *Educational Psychology, 36*(1), 26-46. https://doi.org/10.1080/01443410.2014.895293

Bernard, M. E. (2001). *Program Achieve: A curriculum of lessons for teaching students how to achieve success and develop social-emotional-behavioural well-being.* (2nd ed.).Laguna Beach, California.: You Can Do It Education.

Beveridge, M., & Parkins, E. (1987). Visual representation in analogical problem solving [journal article]. *Memory & Cognition, 15*(3), 230-237. https://doi.org/10.3758/bf03197721

Biggs, J. B., & Collis, K. F. (1982). *Evaluating the quality of learning : the SOLO taxonomy (Structure of the Observed Learning Outcome)*.New York ; London: Academic Press

Bjork, E. L., Little, J. L., & Storm, B. C. (2014). Multiple-choice testing as a desirable difficulty in the classroom. *Journal of Applied Research in Memory and Cognition, 3*(3), 165-170. https://doi.org/http://dx.doi.org/10.1016/j.jarmac.2014.03.002

Blackwell, L. S., Trzesniewski, K. H., & Dweck, C. S. (2007). Implicit theories of intelligence predict achievement across an adolescent transition: A longitudinal study and an intervention. *Child Development, 78*(1), 246-263. https://doi.org/10.1111/j.1467-8624.2007.00995.x

Blume, B. D., Ford, J. K., Baldwin, T. T., & Huang, J. L. (2010). Transfer of training: A meta-analytic review. *Journal of Management, 36*(4), 1065-1105. https://doi.org/10.1177/0149206309352880

Blumenfeld, P. C., & Meece, J. L. (1988). Task factors, teacher behavior, and students' involvement and use of learning strategies in science. *The Elementary School Journal, 88*(3), 235-250. www.jstor.org/stable/1001954

Boden, K. K., Zepeda, C. D., & Nokes-Malach, T. J. (2020). Achievement goals and conceptual learning: An examination of teacher talk. *Journal of Educational Psychology, 112*(6), 1221-1242. https://doi.org/10.1037/edu0000421

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience and school*.Washington, DC: Washington, DC: National Acad. Pr. https://doi.org/10.17226/6160

Bransford, J. D., & Schwartz, D. L. (1999). Chapter 3: Rethinking Transfer: A Simple Proposal With Multiple Implications. *Review of Research in Education, 24*(1), 61-100. https://doi.org/10.3102/0091732x024001061

Brookes, D. T., Ross, B. H., & Mestre, J. P. (2011, 04/07/). Specificity, transfer, and the development of expertise. *Physical Review Special Topics - Physics Education Research, 7*(1), 010105. http://link.aps.org/doi/10.1103/PhysRevSTPER.7.010105

Brown, A. L., & Kane, M. J. (1988). Preschool children can learn to transfer: Learning to learn and learning from example. *Cognitive Psychology, 20*(4), 493-523. https://doi.org/http://dx.doi.org/10.1016/0010-0285(88)90014-X

Bybee, R. W. (2015). *The BSCS 5E instructional model : Creating teachable moments* Arlington, Virginia : NSTA Press.

Cairns, D., & Areepattamannil, S. (2019). Exploring the relations of inquiry-based teaching to science achievement and dispositions in 54 countries. *Research in Science Education, 49*(1), 1-23. https://doi.org/10.1007/s11165-017-9639-x

Calais, G. G. (2006). Haskell's taxonomies of transfer of learning: implications for classroom instruction. *National Forum of Applied Educational Research Journal, 19*(3), 1-8.

Catrambone, R., Craig, D. L., & Nersessian, N. J. (2006). The role of perceptually represented structure in analogical problem solving [journal article]. *Memory & Cognition, 34*(5), 1126-1132. https://doi.org/10.3758/bf03193258

Catrambone, R., & Holyoak, K. J. (1989). Overcoming contextual limitations on problem-solving transfer. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 15*(6), 1147-1156.

CEDA. (2015). *Australia's future workforce?* CEDA. https://cedakenticomedia.blob.core.windows.net/cedamediacontainer/kentico/media/researchcataloguedocuments/research%20and%20policy/pdf/26792-futureworkforce_june2015.pdf

Chase, C. C., Malkiewich, L., & S. Kumar, A. (2019). Learning to notice science concepts in engineering activities and transfer situations. *Science Education, 103*(2), 440-471. https://doi.org/10.1002/sce.21496

Chen, J. A. (2012). Implicit theories, epistemic beliefs, and science motivation: A person-centered approach. *Learning and Individual Differences, 22*(6), 724-735, Article means, z score. https://doi.org/http://dx.doi.org/10.1016/j.lindif.2012.07.013

Chen, J. A., & Pajares, F. (2010). Implicit theories of ability of Grade 6 science students: Relation to epistemological beliefs and academic motivation and achievement in science. *Contemporary Educational Psychology, 35*(1), 75-87, Article path analysis, ANCOVA, t-test. https://doi.org/http://dx.doi.org/10.1016/j.cedpsych.2009.10.003

Chen, Z., & Daehler, M. W. (1992). Intention and outcome: Key components of causal structure facilitating mapping in children's analogical transfer. *Journal of Experimental Child Psychology, 53*(3), 237-257. https://doi.org/http://dx.doi.org/10.1016/0022-0965(92)90038-8

Chi, M. T. H. (2013). Two kinds and four subtypes of misconcepived knowledge, ways to change it and the leanring outcomes. In S. Vosniadou (Ed.), *International Handbook of Research on Conceptual Change* (2nd ed. ed., pp. 49-70). London : Taylor & Francis Group.

Chi, M. T. H., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive Science, 13*(2), 145-182. https://doi.org/http://dx.doi.org/10.1016/0364-0213(89)90002-5

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5*(2), 121-152. https://doi.org/http://dx.doi.org/

Chi, M. T. H., & VanLehn, K. A. (2012). Seeing deep structure from the interactions of surface features. *Educational Psychologist, 47*(3), 177-188. https://doi.org/10.1080/00461520.2012.695709

Chin, C., & Brown, D. E. (2000). Learning in science: A comparison of deep and surface approaches. *Journal of research in science teaching, 37*(2), 109-138. https://doi.org/10.1002/(sici)1098-2736(200002)37:2<109::aid-tea3>3.0.co;2-7

Chung, G. K. w. k., Delacruz, G. C., Dionne, G. B., Baker, E. L., Lee, J. J., & Osmundson, E. (2016). *Towards individualized instruction with technology-enabled tools and methods: an exploratory study* (CRESST report, Issue.

Conner, L. N. (2021). *Integrating STEM in higher education : Addressing global issues*.Milton, United Kingdom: Taylor & Francis Group.

Connolly, N. (2017). *NAP sample assessment science literacy 2015*. A. c. A. a. R. Authority. https://www.nap.edu.au/docs/default-source/default-document-library/20170309-nap_sl_final.pdf?sfvrsn=c4376d5e_2

Cooper, G., & Sweller, J. (1987). Effects of schema acquisition and rule automation on mathematical problem-solving transfer. *Journal of Educational Psychology, 79*(4), 347-362.

Council of Australian Governments Education Council. (2019). *Alice Springs (Mparntwe) education declaration*. Education Services Australia. http://www.educationcouncil.edu.au/site/DefaultSite/filesystem/documents/Reports%20and%20publications/Alice%20Springs%20(Mparntwe)%20Education%20Declaration.pdf

Crisp, V., Johnson, M., & Constantinou, F. (2018). A question of quality: Conceptualisations of quality in the context of educational test questions. *Research in Education, 105*(1), 18-41. https://doi.org/10.1177/0034523717752203

Cui, L., Rebello, N. S., & Bennett, A. G. (2006). College students' transfer from calculus to physics. *AIP Conference Proceedings, 818*(1), 37-40. https://doi.org/10.1063/1.2177017

Day, S. B., & Goldstone, R. L. (2012). The Import of knowledge export: Connecting findings and theories of transfer of learning. *Educational Psychologist, 47*(3), 153-176. https://doi.org/10.1080/00461520.2012.696438

Day, S. B., Motz, B. A., & Goldstone, R. L. (2015). The cognitive costs of context: The effects of concreteness and immersiveness in instructional examples [Original Research]. *Frontiers in Psychology, 6*, 1-13. https://doi.org/10.3389/fpsyg.2015.01876

Deakin Crick, R., & Goldspink, C. (2014). Learner dispositions, self-theories and student engagement. *British Journal of Educational Studies, 62*(1), 19-35. https://doi.org/10.1080/00071005.2014.904038

Deakin Crick, R., Huang, S., Ahmed Shafi, A., & Goldspink, C. (2015). Developing resilient agency in learning: The internal structure of learning power. *British Journal of Educational Studies, 63*(2), 121-160. https://doi.org/10.1080/00071005.2015.1006574

D. f. E. a. C. Development. (2016). *STEM learning strategy for DECD preschool to year 12 2017-2020* Government of South Ausralia.

DECD. (2017a). *Learning design, assessment and moderation strategy overview* Government of South Australia. https://tfelatnps.edublogs.org/files/2018/05/handout-LDAM-strategy-overview-1a1pp8w-rywn0k.pdf

DECD. (2017b). *Reporting on Australian Curriculum in DECD schools Reception - Year 10 v1.0* Government of South Australia. https://myintranet.learnlink.sa.edu.au/library/document-library/controlled-procedures/reporting-on-australian-curriculum-in-decd-schools-reception-to-year-ten-procedure.pdf

DECD. (2016). *Reporting resource A to E guide* Government of South Australia. https://edi.sa.edu.au/library/document-library/controlled-procedures/reporting-on-australian-curriculum-in-department-for-education-schools-reception-to-year-10-procedure/reporting-resource-a-to-e-guide

DECS. (2010). *South Australian teaching for effective learning guide* Government of South Australia, . https://www.decd.sa.gov.au/sites/g/files/net691/f/tfel_framework_guide_complete.pdf

Detterman, D. K. (1993). The case for the prosecution: transfer as an epiphenomenon. In D. K. a. S. Detterman, R.J. (Ed.), *Transfer on Trial: Intelligence, Cognition and Instruction* (pp. 39-67). Ablex Publishing Corp.

DiSessa, A. A. (2002). Why "conceptual ecology" is a good idea. In M. Limon & L. Mason (Eds.), *Reconsidering Conceptual Change: Issues in Theory and Practice* (pp. 29-60). Kluwer Academic Publishers.

DiSessa, A. A. (2004). Metarepresentation: Native competence and targets for instruction. *Cognition and Instruction, 22*(3), 293-331. https://doi.org/10.1207/s1532690xci2203_2

DiSessa, A. A., & Sherin, B. L. (1998). What changes in conceptual change? *International Journal of Science Education, 20*(10), 1155-1191. https://doi.org/10.1080/0950069980201002

DiSessa, A. A., & Wagner, J. F. (2005). What coordination has to say about transfer. In J. p. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. 121-154). Information Age Publishing.

Dori, Y. J., & Sasson, I. (2013). A three-attribute transfer skills framework - part I: establishing the model and its relation to chemical education [10.1039/C3RP20093K]. *Chemistry Education Research and Practice, 14*(4), 363-375. https://doi.org/10.1039/C3RP20093K

Duff, A., & McKinstry, S. (2007). Students' approaches to learning. *Issues in accounting education, 22*(2), 183-214. https://doi.org/10.2308/iace.2007.22.2.183

Dufresne, R., Mestre, J., Thaden-Koch, T. C., Gerace, W. J., & Leonard, W. J. (2005). Knowledge representation and coordination. *AIP Conference Proceedings, 790*(1), 155-215. https://doi.org/doi:http://dx.doi.org/10.1063/1.2084687

Duncker, K. (1945). On problem-solving. *Psychological Monographs: General and Applied, 58*(5), i-113.

Dweck, C. S., & Yeager, D. S. (2019). Mindsets: A view from two eras. *Perspectives on Psychological Science, 14*(3), 481-496. https://doi.org/10.1177/1745691618804166

Ellis, A. B. (2007). A taxonomy for categorizing generalizations: Generalizing actions and reflection generalizations. *Journal of the Learning Sciences, 16*(2), 221-262. https://doi.org/10.1080/10508400701193705

Ellis, H. C. (1965). *The transfer of learning*.New York, USA: The MacMillan Company.

Engle, R. A. (2006). Framing interactions to foster generative learning: A situative explanation of transfer in a community of learners classroom. *Journal of the Learning Sciences, 15*(4), 451-498. https://doi.org/10.1207/s15327809jls1504_2

Engle, R. A. (2012). The resurgence of research Into transfer: An introduction to the final articles of the transfer strand. *Journal of the Learning Sciences, 21*(3), 347-352. https://doi.org/10.1080/10508406.2012.707994

Engle, R. A., Lam, D. P., Meyer, X. S., & Nix, S. E. (2012). How does expansive framing promote transfer? Several proposed explanations and a research agenda for investigating them. *Educational Psychologist, 47*(3), 215-231. https://doi.org/10.1080/00461520.2012.695678

Farmer, T. W. (2020). Reforming research to support culturally and ecologically responsive and developmentally meaningful practice in schools. *Educational Psychologist, 55*(1), 32-39. https://doi.org/10.1080/00461520.2019.1698298

Fauth, B., Wagner, W., Bertram, C., Gollner, R., Roloff, J., Ludtke, O., Polikoff, M., Klusmann, U., & Trautwein, U. (2020). Don't blame the teacher? The need to account for classroom characteristics in evaluations of teaching quality. *J Educ Psychol, 112*(6), 1284-1302. https://doi.org/10.1037/edu0000416

Fong, G. T., Krantz, D. H., & Nisbett, R. E. (1986, 7//). The effects of statistical training on thinking about everyday problems. *Cognitive Psychology, 18*(3), 253-292. https://doi.org/http://dx.doi.org/10.1016/0010-0285(86)90001-0

Forbus, K. D., Gentner, D., & Law, K. (1995). MAC/FAC: A model of similarity-based retrieval. *Cognitive Science, 19*(2), 141-205. https://doi.org/10.1207/s15516709cog1902_1

Fort, D. G., Herr, T. M., Shaw, P. L., Gutzman, K. E., & Starren, J. B. (2017). Mapping the evolving definitions of translational research. *Journal of clinical and translational science, 1*(1), 60-66. https://doi.org/10.1017/cts.2016.10

Foster, M. (2020). *Developing student agency In South Australia seeing our learners anew - "Don't waste a crisis"*. Qatar foundation. Retrieved 26/10/2021 from https://www.wise-qatar.org/developing-student-agency-in-south-australia-seeing-our-learners-anew-dont-waste-a-crisis/

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: potential of the concept, state of the evidence. *Review of Educational Research, 74*(1), 59-109. https://doi.org/10.3102/00346543074001059

Gabriel, F., Signolet, J., & Westwell, M. (2018). A machine learning approach to investigating the effects of mathematics dispositions on mathematical literacy. *International Journal of Research & Method in Education, 41*(3), 306-327. https://doi.org/10.1080/1743727X.2017.1301916

Gagne, R. M. (1965). *The conditions of learning and theory of instruction* (1st ed.).New York, NY: Holt, Rhinehart and Winston.

Geake, J. G. (2009). *The brain at school*.Maidenhead, Berkshire, England: McGraw- Hill Education, Open University Press.

Gee, K. A., & Wong, K. K. (2012). A cross national examination of inquiry and its relationship to student performance in science: Evidence from the Program for International Student Assessment (PISA) 2006. *International Journal of Educational Research, 53*(0), 303-318. https://doi.org/http://dx.doi.org/10.1016/j.ijer.2012.04.004

Gentner, D., & Holyoak, K. J. (1997). Reasoning and learning by analogy. *American Psychologist, 52*(1), 32-34.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology, 12*(3), 306-355. https://doi.org/http://dx.doi.org/10.1016/0010-0285(80)90013-4

Gick, M. L., & Holyoak, K. J. (1983). Schema induction and analogical transfer. *Cognitive Psychology, 15*(1), 1-38. https://doi.org/http://dx.doi.org/10.1016/0010-0285(83)90002-6

Gick, M. L., & Paterson, K. (1992). DO contrasting examples facilitate schema acquisition and analogical transfer? *Canadian Journal of Psychology, 46*(4), 539-550.

Göçmençelebi, Ş. İ., Özkan, M., & Bayram, N. (2012). Evaluating primary school students' deep learning approach to science lessons. *International Online Journal of Educational Sciences, 4* (3), 554-562.

Goetz, E. T., & Sadoski, M. (1995). The perils of seduction - distracting details of incomprehensible abstractions. *Reading Research Quarterly, 30*(3), 500-511. https://doi.org/10.2307/747628

Goldstone, R. L., & Day, S. B. (2012). Introduction to "New Conceptualizations of Transfer of Learning". *Educational Psychologist, 47*(3), 149-152. https://doi.org/10.1080/00461520.2012.695710

Goldstone, R. L., & Son, J. Y. (2005). The transfer of scientific principles using concrete and idealized simulations. *Journal of the Learning Sciences, 14*(1), 69-110. https://doi.org/10.1207/s15327809jls1401_4

Gooding, J., & Metz, B. (2011). From misconceptions to conceptual change. *The Science Teacher, 78*(4), 34-37.

Gott, S. P., Parker Hall, E., Pokorny, R. A., Dibble, E., & Glaser, R. (1993). A naturalistic study of transfer: Adaptive expertise in technical domains. In D. K. a. S. Detterman, R.J. (Ed.), *Transfer on Trial: Intelligence, Cognition and Instruction* (pp. 258-288). Ablex Publishing Corp.

Government of South Australia, D. f. E. (2014). *Australian curriculum SA teachers and leaders resource*. Government of South Australia. Retrieved 29 November, 2021 from https://acleadersresource.sa.edu.au/resources/sa-learning-design/

Grant, E. R., & Spivey, M. J. (2003). Eye movements and problem solving: Guiding attention guides thought. *Psychological Science, 14*(5), 462-466. https://doi.org/10.1111/1467-9280.02454

Gray, K. E., & Rebello, N. S. (2005). Transfer between paired problems in an interview. *AIP Conference Proceedings, 790*(1), 157-160. https://doi.org/10.1063/1.2084725

Greene, J. A., Chinn, C. A., & Deekens, V. M. (2021). Experts' reasoning about the replication crisis: Apt epistemic performance and actor-oriented transfer. *Journal of the Learning Sciences*, 1-50. https://doi.org/10.1080/10508406.2020.1860992

Greeno, J. G. (2006). Authoritative, accountable positioning and connected, general knowing: progressive themes in understanding transfer. *Journal of the Learning Sciences, 15*(4), 537-547. https://doi.org/10.1207/s15327809jls1504_4

Greeno, J. G., Smith, D. R., & Moore, J. M. (1993). Transfer of situated learning. In D. K. a. S. Detterman, R.J. (Ed.), *Transfer on Trial: Intelligence, Cognition and Instruction* (pp. 99-167). Ablex Publishing Corp.

Grose, R. F., & Birney, R., C. (1963). *Transfer of learning* Princeton, New Jersey, USA: D. Van Nostrand Company Inc.

Hackling, M. W. (2008). *An overview of Primary Connections. Stage 3 research outcomes 2006-2008*. Australian Academy of Science. file:///C:/Users/Anne/Downloads/An%20overview%20of%20PrimaryConnections%20Stage%203%20(1).pdf

Hager, P., & Hodkinson, P. (2009). Moving beyond the metaphor of transfer of learning. *British Educational Research Journal, 35*(4), 619-638. https://doi.org/10.1080/01411920802642371

Hajian, S. (2019). Transfer of learning and teaching: A review of transfer theories and effective instructional practices. *IAFOR journal of education, 7*(1), 93-111. https://doi.org/10.22492/ije.7.1.06

Halpern, D. F. (1998). Teaching critical thinking for transfer across domains: Dispositions, skills, structure training, and metacognitive monitoring. *The American psychologist, 53*(4), 449-455. https://doi.org/10.1037/0003-066X.53.4.449

Halpern, D. F., & Hakel, M. D. (2003). Applying the science of learning to the university and beyond. *Change*, *35*(4), 36-41.

Hammer, D., Elby, A., Scherr, R., & Redish, E. F. (2005). Resources, framing and transfer. In J. P. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. 89-119). Information Age Publishing.

Harp, S. F., & Mayer, R. E. (1998). How seductive details do their damage: A theory of cognitive interest in science learning. *Journal of Educational Psychology, 90*(3), 414-434.

Hart, W., & Albarracín, D. (2009). What I was doing versus what I did: Verb aspect influences memory and future actions. *Psychological Science, 20*(2), 238-244. https://doi.org/10.1111/j.1467-9280.2009.02277.x

Hartmann, C., van Gog, T., Rummel, N., Leerstoel van, G., Education, & Learning: Development in, I. (2021). Preparatory effects of problem solving versus studying examples prior to instruction. *Instructional Science, 49*(1), 1-21. https://doi.org/10.1007/s11251-020-09528-z

Haskell, R. E. (2004). Transfer of learning. In C. D. Spielberger (Ed.), *Encyclopedia of Applied Psychology* (pp. 575-586). Elsevier. https://doi.org/https://doi.org/10.1016/B0-12-657410-3/00834-5

Haslerud, G. M., & Meyers, S. (1958). The transfer value of given and individually derived principles. *Journal of Educational Psychology, 49*(6), 293-298.

Hatano, G., & Greeno, J. G. (1999). Commentary: alternative perspectives on transfer and transfer studies. *International Journal of Educational Research, 31*(7), 645-654. https://doi.org/http://dx.doi.org/10.1016/S0883-0355(99)00029-4

Hattie, J. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement*.London: London: Routledge. https://doi.org/10.4324/9780203887332

Hattie, J., & Yates, G. C. R. (2014). *Visible learning and the science of how we learn*.London: London: Routledge. https://doi.org/10.4324/9781315885025

Helfenstein, S. (2006). *Transfer: review, reconstruction, resolution.* University of Jyvaskyla]. Jyvaskyla.

Helfenstein, S., & Saariluoma, P. (2005). Mental contents in transfer [journal article]. *Psychological Research, 70*(4), 293-303. https://doi.org/10.1007/s00426-005-0214-0

Helfenstein, S., & Saariluoma, P. (2007). Apperception in primed problem solving. *Cognitive Processing, 8*(4), 211-232. https://doi.org/10.1007/s10339-007-0189-4

Hendrickson, G., & Schroeder, W. H. (1941). Transfer of training in learning to hit a submerged target. [Article]. *Journal of Educational Psychology 32*(3), 205-213.

Hickey, D. T., Taasoobshirazi, G., & Cross, D. (2012). Assessment as learning: Enhancing discourse, understanding, and achievement in innovative science curricula. *Journal of research in science teaching, 49*(10), 1240-1270. https://doi.org/10.1002/tea.21056

Holyoak, K. J., & Koh, K. (1987). Surface and structural similarity in analogical transfer [journal article]. *Memory & Cognition, 15*(4), 332-340. https://doi.org/10.3758/bf03197035

Holyoak, K. J., & Thagard, P. (1997). The analogical mind. *American Psychologist, 52*(1), 35-44.

Hsu, C.-Y., Kalyuga, S., & Sweller, J. (2015). When should guidance be presented in physics instruction? *Archives of Scientific Psychology, 3*(1), 37-53. https://doi.org/10.1037/arc0000012

Hu, W., Jia, X., Plucker, J. A., & Shan, X. (2016). Effects of a critical thinking skills program on the learning motivation of primary school students. *Roeper Review, 38*(2), 70-83. https://doi.org/10.1080/02783193.2016.1150374

International Association for the Evaluation of Educational Achievement (IAC). (2013). *TIMSS 2011 assessment released science items Grade 4*. https://nces.ed.gov/timss/pdf/TIMSS2011_G4_Science.pdf

Irvine, J. (2017). A comparison of revised bloom and marzano's new taxonomy of learning. *Research in Higher Education Journal, 33*, 1-16.

Jaakkola, T., & Veermans, K. (2018). Exploring the effects of concreteness fading across grades in elementary school science education. *Instructional Science, 46*(2), 185-207. https://doi.org/10.1007/s11251-017-9428-y

Jacot, A., Raemdonck, I., & Frenay, M. (2015). A review of motivational constructs in learning and training transfer [journal article]. *Zeitschrift für Erziehungswissenschaft, 18*(1), 201-219. https://doi.org/10.1007/s11618-014-0599-x

Judd, C. H. (1908). The relationship of special training to general intelligence. *Educational Review, 36*, 28-42.

Kachergis, G., Rhodes, M., & Gureckis, T. (2017). Desirable difficulties during the development of active inquiry skills. *Cognition, 166*, 407-417. https://doi.org/https://doi.org/10.1016/j.cognition.2017.05.021

Kaminski, J. A., Sloutsky, V. M., & Heckler, A. F. (2013). The cost of concreteness: The effect of nonessential information on analogical transfer. *Journal of Experimental Psychology: Applied, 19*(1), 14-29.

Kaplan, A., Gheen, M., & Midgley, C. (2002, Jun). Classroom goal structure and student disruptive behaviour. *Br J Educ Psychol, 72*(Pt 2), 191-211.

Kappes, H. B., Stephens, E. J., & Oettingen, G. (2011). Implicit theories moderate the relation of positive future fantasies to academic outcomes. *Journal of Research in Personality, 45*(3), 269-278. https://doi.org/http://dx.doi.org/10.1016/j.jrp.2011.02.006

Kapur, M. (2015). Learning from productive failure. *Learning: Research and Practice, 1*(1), 51-65. https://doi.org/10.1080/23735082.2015.1002195

Kapur, M., & Bielaczyc, K. (2011). Designing for productive failure. *Journal of the Learning Sciences, 21*(1), 45-83. https://doi.org/10.1080/10508406.2011.591717

Katona, G. (1942). On different forms of learning by reading. *Journal of Educational Psychology, 33*(5), 335-355.

Keane, M. (1987). On retrieving analogues when solving problems. *The Quarterly Journal of Experimental Psychology Section A, 39*(1), 29-41. https://doi.org/10.1080/02724988743000015

Kember, D., Biggs, J., & Leung, D. Y. P. (2004). Examining the multidimensionality of approaches to learning through the development of a revised version of the Learning Process Questionnaire. *British Journal of Educational Psychology, 74*, 261-279. http://search.proquest.com/docview/216965917?accountid=10910

Kesidou, S., Sadeghi, R., & Marosszeky, N. (2013). *National Assessment Program - science literacy school release materials*. A. a. R. A. Australian Curriculum. http://www.nap.edu.au/_resources/NAP-SL_2012_School_Release_Materials.pdf

Kesidou, S., Sadeght, R and Marosszeky, N. (2012). *National Assessment Program - science literacy year 6 report*. ACARA. http://www.nap.edu.au/verve/_resources/NAP-SL_2012_Public_Report.pdf

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006, 2006/06/01). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75-86. https://doi.org/10.1207/s15326985ep4102_1

Kohn, M. S. (2016). *Factors that inhibit or facilitate transfer of learning: A replication study* [Ph.D., Capella University]. ProQuest Dissertations & Theses Global. Ann Arbor.

Kornilova, T. V., Kornilov, S. A., & Chumakova, M. A. (2009). Subjective evaluations of intelligence and academic self-concept predict academic achievement: Evidence from a selective student population. *Learning and Individual Differences, 19*(4), 596-608. https://doi.org/http://dx.doi.org/10.1016/j.lindif.2009.08.001

Kruit, P. M., Oostdam, R. J., van den Berg, E., & Schuitema, J. A. (2018). Effects of explicit instruction on the acquisition of students' science inquiry skills in grades 5 and 6 of primary education. *International Journal of Science Education, 40*(4), 421-441. https://doi.org/10.1080/09500693.2018.1428777

Kurtz, K. J., & Loewenstein, J. (2007). Converging on a new role for analogy in problem solving and retrieval: when two problems are better than one [journal article]. *Memory & Cognition, 35*(2), 334-341. https://doi.org/10.3758/bf03193454

Larsen-Freeman, D. (2013). Transfer of learning transformed. *Language Learning, 63*, 107-129. https://doi.org/10.1111/j.1467-9922.2012.00740.x

Lave, J. (1988). *Cognition in practice: mind, mathematics and culture in everyday life*.Cambridge, New York: Cambridge University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*.Cambridge, England: Cambridge University Press.

Law, Y. K., Chan, C. K., & Sachs, J. (2008, Mar). Beliefs about learning, self-regulated strategies and text comprehension among Chinese children. *Br J Educ Psychol, 78*(Pt 1), 51-73. https://doi.org/10.1348/000709907x179812

Leberman, S., McDonald, L., & Doyle, S. (2016). *The transfer of learning. Participant's Perspectives of adult education and training*.Alserchot, Hampshire, England: Gower Publishing Company.

Leimbach, M. (2010). Learning transfer model: a research-driven approach to enhancing learning effectiveness. *Industrial and Commercial Training, 42*(2), 81-86. https://doi.org/http://dx.doi.org/10.1108/00197851011026063

Levrini, O., & diSessa, A. A. (2008). How students learn from multiple contexts and definitions: Proper time as a coordination class. *Physical Review Special Topics - Physics Education Research, 4*(1), 010107. http://link.aps.org/doi/10.1103/PhysRevSTPER.4.010107

Levrini, O., Fantini, P., Tasquier, G., Pecori, B., & Levin, M. (2015). Defining and operationalizing appropriation for science learning. *Journal of the Learning Sciences, 24*(1), 93-136. https://doi.org/10.1080/10508406.2014.928215

Lipko-Speed, A., Dunlosky, J., & Rawson, K. A. (2014). Does testing with feedback help grade-school children learn key concepts in science? *Journal of Applied Research in Memory and Cognition, 3*(3), 171-176. https://doi.org/http://dx.doi.org/10.1016/j.jarmac.2014.04.002

Litchfield, D., & Ball, L. J. (2011). Using another's gaze as an explicit aid to insight problem solving. *The Quarterly Journal of Experimental Psychology, 64*(4), 649-656. https://doi.org/10.1080/17470218.2011.558628

Lobato, J. (2006). Alternative perspectives on the transfer of learning: History, issues, and challenges for future research. *Journal of the Learning Sciences, 15*(4), 431-449. https://doi.org/10.1207/s15327809jls1504_1

Lobato, J. (2012). The actor-oriented transfer perspective and its contributions to educational research and practice. *Educational Psychologist, 47*(3), 232-247. https://doi.org/10.1080/00461520.2012.693353

Lobato, J., Rhodehamel, B., & Hohensee, C. (2012). “Noticing” as an alternative transfer of learning process. *Journal of the Learning Sciences, 21*(3), 433-482. https://doi.org/10.1080/10508406.2012.682189

Maciejewski, W., & Merchant, S. (2016). Mathematical tasks, study approaches, and course grades in undergraduate mathematics: a year-by-year analysis. *International Journal of Mathematical Education in Science and Technology, 47*(3), 373-387. https://doi.org/10.1080/0020739X.2015.1072881

Mandler, J. M., & Orlich, F. (2013). Analogical transfer: The roles of schema abstraction and awareness [journal article]. *Bulletin of the Psychonomic Society, 31*(5), 485-487. https://doi.org/10.3758/bf03334970

Martin, A. J., Mansour, M., & Malmberg, L.-E. (2020). What factors influence students’ real-time motivation and engagement? An experience sampling study of high school students using mobile technology. *Educational Psychology, 40*(9), 1113-1135. https://doi.org/10.1080/01443410.2018.1545997

Marton, F. (2006). Sameness and difference in transfer. *Journal of the Learning Sciences, 15*(4), 499-535. https://doi.org/10.1207/s15327809jls1504_3

Marzano, R. J., & Kendall, J. S. (2007). *The new taxonomy of educational objectives*.Thousand Oaks, CA, U.S.A.: Corwin press.

Mayer, R. E. (1975). Information processing variables in learning to solve problems. *Review of Educational Research, 45*(4), 525-541. https://doi.org/10.3102/00346543045004525

McCullum, C. C. (2017). *An examination of the factors that influence the transfer of learning among k-12 educators participating in professional learning communities (Doctoral dissertation)* (Publication Number 10620576) [Ed.D., The University of Southern Mississippi]. ProQuest Central; ProQuest Dissertations & Theses Global; Social Science Premium Collection. Ann Arbor.

McDaniel, M. A., Thomas, R. C., Agarwal, P. K., McDermott, K. B., & Roediger, H. L. (2013). Quizzing in middle-school science: Successful Transfer performance on classroom exams. *Applied Cognitive Psychology, 27*(3), 360-372. https://doi.org/10.1002/acp.2914

McKeachie, W. J. (1987). Cognitive skills and their transfer: Discussion. *International Journal of Educational Research, 11*(6), 707-712. https://doi.org/10.1016/0883-0355(87)90010-3

Melo, M., & Miranda, G. l. (2015). Learning electrical circuits: The effects of 4c-id instructional approach in the acquision and transfer of knowledge. *Journal of Information Technology Education: Research 14*, 313-337.

Mestre, J. (2005). Is Transfer ubiquitous or rare? New paradigms for studying transfer. *AIP Conference Proceedings, 790*(1), 3-6. https://doi.org/doi:http://dx.doi.org/10.1063/1.2084687

Mestre, J. P. (2002). Probing adults' conceptual understanding and transfer of learning via problem posing. *Journal of Applied Developmental Psychology, 23*(1), 9-50. https://doi.org/http://dx.doi.org/10.1016/S0193-3973(01)00101-0

Mestre, J. P., Dufresne, R. J., Gerace, W. J., Hardiman, P. T., & Touger, J. S. (1993). Promoting skilled problem-solving behavior among beginning physics students. *Journal of research in science teaching, 30*(3), 303-317. https://doi.org/10.1002/tea.3660300306

Middleton, M., & Midgley, C. (1997). Avoiding the demonstration of lack of ability: An underexplored aspect of goal theory. *Journal of Educational Psychology 89*(4), 710-718.

Miki, K., & Yamauchi, H. (2005). Perceptions of classroom goal structures, personal achievement goal orientations, and learning strategies. *The Japanese Journal of Psychology, 76*(3), 260-268.

Mitchell, P. (2016). *From concept to classroom: What is translational research*. Australian Council for Educational Research. https://research.acer.edu.au/professional_dev/9

Nikata, K., & Shimada, H. (2005). Facilitation of analogical transfer by posing an analogous problem for oneself. *The Japanese Journal of Educational Psychology, 53*(3), 381-392. https://doi.org/10.5926/jjep1953.53.3_381

Nokes-Malach, T. J., & Mestre, J. P. (2013). Toward a model of transfer as sense-making. *Educational Psychologist, 48*(3), 184-207. https://doi.org/10.1080/00461520.2013.807556

Nokes-Malach, T. J., VanLehn, K., Belenky, D. M., Lichtenstein, M., & Cox, G. (2012). Coordinating principles and examples through analogy and self-explanation [journal article]. *European Journal of Psychology of Education, 28*(4), 1237-1263. https://doi.org/10.1007/s10212-012-0164-z

Nokes, T. J. (2009). Mechanisms of knowledge transfer. *Thinking & Reasoning, 15*(1), 1-36. https://doi.org/10.1080/13546780802490186

Ohlsson, S. (2009). Resubsumption: A possible mechanism for conceptual change and belief revision. *Educational Psychologist, 44*(1), 20-40. https://doi.org/10.1080/00461520802616267

Ohlsson, S. (2011). *Deep learning : How the mind overrides experience*.New York: Cambridge University Press.

Ozdemir, O. F. (2013). Transfer and conceptual change: the change process from the theoretical perspectives of coordination classes and phenomenological primitives. *Instructional Science, 41*(1), 81-103. https://doi.org/10.1007/s11251-012-9219-4

Panizzon, D., Arthur, D., & Pegg, J. (2006). ESSA: Developing and scoping a test to explore scientific literacy and achievement in NSW. *Teaching Science, 52*(4), 22-27.

Paulick, I., Retelsdorf, J., & Möller, J. (2013). Motivation for choosing teacher education: Associations with teachers' achievement goals and instructional practices. *International Journal of Educational Research, 61*, 60-70. https://doi.org/http://dx.doi.org/10.1016/j.ijer.2013.04.001

Pedone, R., Hummel, J., & Holyoak, K. (2001). The use of diagrams in analogical problem solving. *Memory & Cognition, 29*(2), 214-221. https://doi.org/10.3758/bf03194915

Pegg, J., & Tall, D. (2005). The fundamental cycle of concept construction underlying various theoretical frameworks. *ZDM, 37*(6), 468-475. https://doi.org/10.1007/BF02655855

Perkins, D. (2009). *Making learning whole : how seven principles of teaching can transform education* (1 ed.). Wiley. http://flinders.eblib.com/patron/FullRecord.aspx?p=487701

Perkins, D. N., & Salomon, G. (1992). Transfer of learning. In *International Encyclopaedia of Education*. Pergammon Press. https://learnweb.harvard.edu/alps/thinking/docs/traencyn.htm

Perkins, D. N., & Salomon, G. (2012). Knowledge to go: A motivational and dispositional view of transfer. *Educational Psychologist, 47*(3), 248-258. https://doi.org/10.1080/00461520.2012.693354

Peters, L. W. H., ten Dam, G. T. M., Kocken, P. L., Buijs, G. J., Dusseldorp, E., & Paulussen, T. G. W. M. (2015). Effects of transfer-oriented curriculum on multiple behaviors in the Netherlands. *Health Promotion International, 30*(2), 291-309. https://doi.org/10.1093/heapro/dat039

Raaijmakers, S. F., Baars, M., Paas, F., van Merriënboer, J. J. G., & van Gog, T. (2018). Training self-assessment and task-selection skills to foster self-regulated learning: Do trained skills transfer across domains? *Applied Cognitive Psychology, 32*(2), 270-277. https://doi.org/https://doi.org/10.1002/acp.3392

Ramburuth, P., & Mladenovic, R. (2004). Exploring the relationship between students' orientations to learning, the structure of students' learning outcomes and subsequent academic performance. *Accounting Education, 13*(4), 507-527. https://doi.org/10.1080/0963928042000306774

Ramos, A., De Fraine, B., & Verschueren, K. (2021). Learning goal orientation in high-ability and average-ability students: Developmental trajectories, contextual predictors, and long-term educational outcomes. *Journal of Educational Psychology, 113*(2), 370-389. https://doi.org/10.1037/edu0000476

Rappolt-Schlichtmann, G., Daley, S. G., Lim, S., Lapinski, S., Robinson, K. H., & Johnson, M. (2013). Universal design for learning and elementary school science: Exploring the efficacy, use, and perceptions of a web-based science notebook. *Journal of Educational Psychology, 105*(4), 1210-1225.

Rebello, N. S., Zollman, D. A., Allbaugh, A. R., Engelhardt, P. V., Gray, K. E., Hrepic, Z., & Itza-Ortiz, S. F. (2005). Dynamic transfer. In J. P. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. 217-250). Information Age Publishing.

Reed, S. K. (2015). The structure of ill-structured (and well-structured) problems revisited [journal article]. *Educational Psychology Review*, 1-26. https://doi.org/10.1007/s10648-015-9343-1

Reed, S. K., Dempster, A., & Ettinger, M. (1985). Usefulness of analogous solutions for solving algebra word problems. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 11*(1), 106-125.

Resnick, L. B. (1989). Introduction. In L. B. Resnick (Ed.), *Knowing, learning and instruction. Essays in honor of Robert Glaser* (pp. 1-24). Luwrence Erlbaum and Associates.

Richey, J. E., & Nokes-Malach, T. J. (2013). How much is too much? Learning and motivation effects of adding instructional explanations to worked examples. *Learning and Instruction, 25*, 104-124. https://doi.org/http://dx.doi.org/10.1016/j.learninstruc.2012.11.006

Richland, L. E., Stigler, J. W., & Holyoak, K. J. (2012). Teaching the conceptual structure of mathematics. *Educational Psychologist, 47*(3), 189-203. https://doi.org/10.1080/00461520.2012.667065

Roid, G. (2003). *Stanford-Binet intelligence scales - SB5*.Austin, Texas, USA: Pro Ed.

Roorda, G., Vos, P., & Goedhart, M. J. (2015). An actor-oriented transfer perspective on high school students' development of the use of procedures to solve problems on rate of change. [journal article]. *International Journal of Science and Mathematics Education, 13*(4), 863-889. https://doi.org/10.1007/s10763-013-9501-1

Royer, J. M. (1979). Theories of the transfer of learning. *Educational Psychologist, 14*(1), 53-69. https://doi.org/10.1080/00461527909529207

Royer, J. M., Mestre, J. P., & Dufresne, R. J. (2005). Framing the transfer problem. In J. P. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. vi-xxvi). Information Age Publishing.

Sadler, P. M., Sonnert, G., Coyle, H. P., Cook-Smith, N., & Miller, J. L. (2013). The influence of teachers' knowledge on student learning in middle school physical science classrooms. *American Educational Research Journal*, Article R and other. https://doi.org/10.3102/0002831213477680

Salomon, G., & Perkins, D. N. (1989). Rocky roads to transfer: Rethinking mechanism of a neglected phenomenon. *Educational Psychologist, 24*(2), 113-142. https://doi.org/10.1207/s15326985ep2402_1

Schwartz, D. L., Bransford, J. D., & Sears, D. (2005). Efficiency and innovation in transfer. *Transfer of learning from a modern multidisciplinary perspective*, 1-51.

Schwartz, D. L., Chase, C. C., & Bransford, J. D. (2012). Resisting overzealous transfer: Coordinating previously successful routines with needs for new learning. *Educational Psychologist, 47*(3), 204-214. https://doi.org/10.1080/00461520.2012.696317

Schwartz, D. L., Chase, C. C., Oppezzo, M. A., & Chin, D. B. (2011). Practicing Versus Inventing With Contrasting Cases: The Effects of Telling First on Learning and Transfer. *Journal of Educational Psychology, 103*(4), 759-775.

Schwartz, D. L., & Martin, T. (2004). Inventing to Prepare for Future Learning: The Hidden Efficiency of Encouraging Original Student Production in Statistics Instruction. *Cognition and Instruction, 22*(2), 129-184. https://doi.org/10.1207/s1532690xci2202_1

Science teaching reconsidered a handbook. (1997).Washington, D.C.: National Academy Press.

Shea, P., Gozza-Cohen, M., Uzuner, S., Mehta, R., Valtcheva, A. V., Hayes, S., & Vickers, J. (2011). The Community of Inquiry framework meets the SOLO taxonomy: a process-product model of online learning. *Educational Media International, 48*(2), 101-113. https://doi.org/10.1080/09523987.2011.576514

Singley, M. K., & Anderson, J. R. (1989). *The transfer of cognitive skill*.Cambridge, Massachussets, USA: Harvard University Press.

Sisk, V. F., Burgoyne, A. P., Sun, J., Butler, J. L., & Macnamara, B. N. (2018). To what extent and under which circumstances are growth mind-sets important to academic achievement? Two meta-analyses. *Psychological Science, 29*(4), 549-571. https://doi.org/10.1177/0956797617739704

Slavin, R., Drake, C., Hanley, P., & Thurston, A. (2012). Effective programs for elementary science: a best evidence synthesis. *Best Evidence Encyclopaedia*. http://www.bestevidence.org.uk/reviews/primary_science/index.html

Snoddy, S. P. (2018). *Preventing inert knowledge: Category status promotes spontaneous structure-based retrieval of prior knowledge* (Publication Number 10792540) [M.S., State University of New York at Binghamton]. ProQuest Dissertations & Theses Global. Ann Arbor.

Son, J. Y., & Goldstone, R. L. (2009). Contextualization in perspective. *Cognition and Instruction, 27*(1), 51-89. www.jstor.org/stable/27739901

South Australia. Education, D. (1992). *Attainment levels*.Adelaide]: Adelaide : Education Dept. of South Australia.

Spencer, R. M., & Weisberg, R. W. (1986). Context-dependent effects on analogical transfer [journal article]. *Memory & Cognition, 14*(5), 442-449. https://doi.org/10.3758/bf03197019

Sternberg, R. J., & French, P. A. (1993). Mechanisms of transfer. In D. K. a. S. Detterman, R.J. (Ed.), *Transfer on Trial: Intelligence, Cognition and Instruction* (pp. 25-38). Ablex Publishing Corp.

Stockard, J., Wood, T. W., Coughlin, C., & Rasplica Khoury, C. (2018). The effectiveness of direct instruction curricula: A meta-analysis of a half century of research. *Review of Educational Research, 88*(4), 479-507. https://doi.org/10.3102/0034654317751919

Suprapto, N. (2020). Do we experience misconceptions?: an ontological review of misconceptions in science. *Studies in Philosophy of Science and Education, 1*, 50-55.

Sweller, J. (2010, Jun 2010

2014-08-22). Element Interactivity and Intrinsic, Extraneous, and Germane Cognitive Load. *Educational Psychology Review, 22*(2), 123-138. https://doi.org/https://doi.org/10.1007/s10648-010-9128-5

Taatgen, N. A. (2013). The nature and transfer of cognitive skills. *Psychol Rev, 120*(3), 439-471. https://doi.org/10.1037/a0033138

Talanquer, V. (2009). On cognitive constraints and learning progressions: The case of “structure of matter”. *International Journal of Science Education, 31*(15), 2123-2136. https://doi.org/10.1080/09500690802578025

Tapola, A., Jaakkola, T., & Niemivirta, M. (2014). The influence of achievement goal orientations and task concreteness on situational interest. *The Journal of Experimental Education, 82*(4), 455-479. https://doi.org/10.1080/00220973.2013.813370

Thaden-Koch, T. C., Dufresne, R. J., & Mestre, J. P. (2006). Coordination of knowledge in judging animated motion. *Physical Review Special Topics - Physics Education Research, 2*(2), 020107. http://link.aps.org/doi/10.1103/PhysRevSTPER.2.020107

Therrien, W. J., Taylor, J. C., Hosp, J. L., Kaldenberg, E. R., & Gorsh, J. (2011). Science Instruction for Students with Learning Disabilities: A Meta-Analysis. *Learning Disabilities Research & Practice, 26*(4), 188-203. https://doi.org/https://doi.org/10.1111/j.1540-5826.2011.00340.x

Thomas, L. E., & Lleras, A. (2009). Covert shifts of attention function as an implicit aid to insight. *Cognition, 111*(2), 168-174. https://doi.org/10.1016/j.cognition.2009.01.005

Thomas, R., & Mady, C. (2014). Teaching for transfer: insights from theory and practices in primary level French second language classrooms. l. *McGill Journal of Education (Online), 49*(2), 399-416.

Thompson, S., De Bortoli, L and Buckley, S. (2013). *PISA 2012: How Australia measures up*. A. C. f. E. R. Ltd. http://www.acer.edu.au/documents/PISA-2012-Report.pdf

Thompson, S., Hillman, K and Wernert, N, Schmid, M, Buckley, S, Munene, A. (2012). *Monitoring Australian Year 4 student achievement internationally:TIMSS 2011*. A. C. f. E. R. Ltd. http://www.acer.edu.au/files/TIMSS-PIRLS_Monitoring-Australian-Year-4-Student-Achievement.pdf

Thorndike, E. L. (1903). The influence of special forms of training on more general abilities. In *Educational Psychology*. New York Teachers College.

Thorndike, E. L. (1924). Mental discipline in high school studies. *Journal of Educational Psychology, 15*(1), 1-22.

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. *Psychological Review., 8*(3), 247-261.

Tonhauser, C., & Laura, B. (2016). Determinants of transfer of training: A comprehensive literature review. *International Journal for Research in Vocational Education and Training, 3*(2), 127-165. https://doi.org/10.13152/IJRVET.3.2.4

Transfer of Learning from a Modern Multidisciplinary Perspective. (2005). (J. P. Mestre, Ed.).Greenwith, U.S.A.: Information Age Publishing.

Trenholm, S. (2021). Media effects accompanying the use of recorded lecture videos in undergraduate mathematics instruction*. *International Journal of Mathematical Education in Science and Technology*, 1-29. https://doi.org/10.1080/0020739X.2021.1930221

Tytler, R. (2019). *Inquiry vs direct teaching for interdisciplinary STEM*. Deakin University, STEME Research Group. Retrieved 11 August 2021 from https://deakinsteme.org/blog/inquiry-vs-direct-teaching-for-interdisciplinary-stem/

Tzohar-Rozen, M., & Kramarski, B. (2017). Metacognition and meta-affect in young students: Does it make a difference in mathematical problem solving? *Teachers College Record, 119*(13).

van den Berg, R. G. (2020). *Effect size - a quick guide*. Retrieved 17/01/2022 from https://www.spss-tutorials.com/effect-size/

van Gog, T., Paas, F., & van Merriënboer, J. J. (2004, Jan 2004

2014-08-09). Process-Oriented Worked Examples: Improving Transfer Performance Through Enhanced Understanding. *Instructional Science, 32*(1-2), 83-98. https://doi.org/https://doi.org/10.1023/B:TRUC.0000021810.70784.b0

Vendetti, M. S., Matlen, B. J., Richland, L. E., & Bunge, S. A. (2015). Analogical reasoning in the classroom: Insights from cognitive science. *Mind, brain and education, 9*(2), 100-106. https://doi.org/10.1111/mbe.12080

Verkade, H., Mulhern, T. D., Lodge, J., Elliott, K., Cropper, S., Rubinstein, B., Horton, A., Elliott, C., Espinsos, A., Dooley, L., Frankland, S., Mulder, R., & Livett, M. (2017). *Misconceptions as a trigger for enhancing student learning in higher education.* (Vol. 1).Melbourne, Australia: The University of Melbourne. https://minerva-access.unimelb.edu.au/handle/11343/197958

Vermeulen, R. C. M. (2002). Narrowing the transfer gap: the advantages of "as if" situations in training. *Journal of European Industrial Training, 26*(8), 366-374. https://doi.org/10.1108/03090590210444946

Wang, Z., Ardasheva, Y., & Lin, L. (2021). Does high perceptual load assist in reducing the seductive details effect? *Educational Psychology, 41*(1), 25-44. https://doi.org/10.1080/01443410.2019.1686465

Warshauer, H. K. (2015). Productive struggle in middle school mathematics classrooms [journal article]. *Journal of Mathematics Teacher Education, 18*(4), 375-400. https://doi.org/10.1007/s10857-014-9286-3

Watts, T. W., Clements, D. H., Sarama, J., Wolfe, C. B., Spitler, M. E., & Bailey, D. H. (2017). Does early mathematics intervention change the processes underlying children's learning? *Journal of Research on Educational Effectiveness, 10*(1), 96-115. https://doi.org/10.1080/19345747.2016.1204640

Webb, N. L. (1997). *Criteria for alignment of expectations and assessments in mathematics and science education* (Research Monograph, Issue. C. o. C. S. S. Officers & A. Publications.

Webb, N. L. (2002). *Depth of knowledge levels for four content areas.* Wisconsin Centrefor Education Research, University of Wisconsin-Madison.

Webb, N. L. (2007). Issues related to judging the alignment of curriculum standards and assessments. *Applied Measurement in Education, 20*(1), 7-25. https://doi.org/10.1080/08957340709336728

Westwood, P. (2005). *Spelling. Approaches to teaching and assessment - Second edition*.Melbourne, Australia: ACER Press.

Whittington, C. (1986). Literature review: Transfer of learning in social work education. *The British Journal of Social Work, 16*(5), 571-577. www.jstor.org/stable/23705650

Wiliam, D. (2010). Episode 2. *The classroom experiment*.

Wiliam, D. (2018). *Embedded formative assessment* (Second edition. ed.) Bloomington, Indiana : Solution Tree Press.

Wolfe, C. R., Reyna, V. F., & Sears, D. (2005). Fuzzy-trace theory: Implications for transfer in teaching and learning. In J. P. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. 53-88). Information Age Publishing.

Woltz, D. J., Gardner, M. K., & Gyll, S. P. (2000, 9//). The role of attention processes in near transfer of cognitive skills. *Learning and Individual Differences, 12*(3), 209-251. https://doi.org/http://dx.doi.org/10.1016/S1041-6080(01)00038-3

Woodworth, R. S. (1972). *Woodworth & Schlosberg's Experimental psychology* (3d ed. [by] J. W. Kling & Lorrin A. Riggs and seventeen contributors. ed.).London: London, Methuen.

Woodworth, R. S., & Thorndike, E. L. (1901). The influence of improvement in one mental function upon the efficiency of other functions. (I). *Psychological Review, 8*(3), 247-261. https://doi.org/10.1037/h0074898

Woolf, S. H. (2008). The meaning of translational research and why It matters. *JAMA, 299*(2), 211-213. https://doi.org/10.1001/jama.2007.26

Wu, Y.-J., Carstensen, C. H., & Lee, J. (2020, 2020/05/27). A new perspective on memorization practices among East Asian students based on PISA 2012. *Educational Psychology, 40*(5), 643-662. https://doi.org/10.1080/01443410.2019.1648766

Yang, Y.-T. C. (2012, 11//). Cultivating critical thinkers: Exploring transfer of learning from pre-service teacher training to classroom practice. *Teaching and Teacher Education, 28*(8), 1116-1130. https://doi.org/http://dx.doi.org/10.1016/j.tate.2012.06.007

Yelon, S. (1992). M.A.S.S.: A model for producing transfer. *Performance Improvement Quarterly, 5*(2), 13-23. https://doi.org/10.1111/j.1937-8327.1992.tb00542.x

Zepeda, C. D., Richey, J. E., Ronevich, P., & Nokes-Malach, T. J. (2015). Direct instruction of metacognition benefits adolescent science learning, transfer, and motivation: an in vivo study. *Journal of Educational Psychology, 107*(4), 954-970.

Zhang, D., Koda, K., & Leong, C. K. (2016, 2016/03/01). Morphological awareness and bilingual word learning: a longitudinal structural equation modeling study. *Reading and Writing, 29*(3), 383-407. https://doi.org/10.1007/s11145-015-9603-y

Zvoch, K., Holveck, S., & Porter, L. (2021). Teaching for conceptual change in a density unit provided to seventh graders: a comparison of teacher- and student-centered approaches. *Research in Science Education, 51*(5), 1395-1421. https://doi.org/10.1007/s11165-019-09907-8

Appendices

Appendix A – School Materials for Differentiating Learning

Planning for Differentiation – a Guide for Teachers

1. Clarify the concept/learning intention
2. Write a student friendly set of success criteria that include different levels of success
3. Come up with some contexts or examples where it can be applied
4. Choose a context and write a problem-solving prompt with no scaffolding or cues. If possible ask for an explanation.
5. Generate 4 prompts for learners at different stages:
    a. focus question to direct learners to the key learning (for those who might go off on a tangent or miss the point)
    b. scaffold that some students may need to complete the task. Make this stand alone without teacher input if possible (for those unable to meet the success criteria independently)
    c. consolidation question at the same level and using the same or a closely related context. (for those who need more practice or a chance to try it on their own)
    d. extension question which combines this concept with some other learning (for those who clearly have the concept)
6. Plan a lesson sequence involving a confusion zone before a feedback zone, a sharing zone and a reflection zone or equivalent (see lesson zones below)

Lesson Zones

Lesson Zone	Teacher does	Students do
Task clarification	Explain the task, answer any questions about limitations or constraints without hinting at the solution. Point out where students can get access to task and materials	Make sure you understand what you need to produce in response to the task and any limitations
Confusion zone	Observe what students are doing, put out any spot fires by redirecting to task	Have a go. Check back to the task to make sure you haven't gone off track
Feedback zone	After students have attempted a response, offer feedback appropriate to the level of thinking they have demonstrated (see levels of thinking table below)	Act on the feedback by changing or adding to your response.
Sharing zone	Choose a few students demonstrating a range levels to share their thinking and call for responses from the rest of the class about why they might have thought this and how they could have thought differently. Thank all student sharers on behalf of the class	Consider the strengths and limitations of other ideas. What possible alternatives are there?
Reflection zone	Ask a reflection question targeting a particular aspect of the learning – concept or process.	Reflect on an aspect of your learning.

Levels of thinking (based on SOLO)					
Level	**1** Lost/ never found the plot	**2** Knows some stuff but not enough to solve the problem	**3** Knows enough stuff but needs practice in applying it	**4** Has done an application task but not in several different contexts	**5** Has it nailed, (even if presentation needs work)
who	 Pre-structural Patsy	 Unistructural Yanni	 Multi-structural Mary	 Relational Robbie	 Extended abstract Abbie
Identify by …	Missed the point; gone off at a tangent; including done something creative/high level But has not yet engaged with the target learning	Has engaged with the targeted learning But doesn't have enough of the basic underlying knowledge or skills to be able to do the task	Has enough of the underpinning knowledge or skills to do the task But has not applied them to solve the problem in this context	Seems to be able to apply it to solve this problem But has not yet produced evidence of this in similar contexts	Has it nailed; even though the evidence might be lacking in presentation or detail
Also may …	• Produce something irrelevant • Pick up on a personal interest in this context • Refuse to engage with task	• Make a start but doesn't invoke key ideas • Claim it's not possible • Copy others work with limited understanding	• Reproduce rote learnt or copied material • Reluctant to engage if not sure of getting a right answer • Wait for direction rather than attempt by self	• Successfully complete the task with or without assistance from peers or scaffolding from you	• Generate a response that shows they understand how to do it as well as what the learning is used for in this context (and possible other contexts)
Need	Focus	Scaffold/ explicit teaching	Check the success criteria after confusion zone	Consolidation	Extension

Appendix B – A Range of Conceptions of Transfer of Learning

Researcher(s)	Definition/description	What is transferred	Actions of learners	Contexts (where and when)	Reference to similarity or difference
Thorndike (1903, p. 80)	"How far does the training of any mental function improve other functions?"	training of mental function	improve other functions		any/ other
Judd (1908)	"… generalisation of experience"	experience	generalise to	(other) experiences	
Grose and Birney (1963)	"How does previous learning affect subsequent learning?"	learning	affect learning		Previous/ subsequent
Ellis (1965) p3	"… experience or performance on one task influences some subsequent task"	experience, performance	influence performance	task	One/ subsequent
Woodworth (1972)	The carrying over of an act or way of acting from one performance to another	act or way of acting	carry over	performance	One/ another
Singley and Anderson (1989) p29	acquisition of a particular use of knowledge and the range of circumstances over which that use will extend	knowledge	extend use	circumstances	range of
Greeno et al. (1993)	how learning to participate in one activity in one situation can influence (positively or negatively) one's ability to participate in another activity in a different situation	learning from participating in an activity	influence participation	one /another activity in a situation	different
Detterman (1993)	the degree to which a behaviour will be repeated in a new situation	procedural learning	repeat behaviour	new situation	new
Hatano and Greeno (1999)	The generality of learning be referred to as ***productivity*** or productive thinking	learning	Generalise, think productively		

Researcher(s)	Definition/description	What is transferred	Actions of learners	Contexts (where and when)	Reference to similarity or difference
Alexander and Murphy (1999)	process of using knowledge acquired in one situation in some new or novel situation	knowledge	use	situation	One/ new
(Bransford, Brown, & Cocking, 1999) P39	The ability to extend what has been learned in one context to new contexts	what has been learned	extend	context	One/new
Barnett and Ceci (2002)	Framework rather than a definition, featuring nature of skill, performance change and memory demands as well as the distance between training and transfer contexts	skill or performance		context	6 dimensions of near and far
Haskell (2004)	"the use of past learning in the learning of something new and the application of learning to both similar and new situations"	learning	use, apply	situations	similar and new Past/ new
Schwartz et al. (2005)	preparation for future learning	learning	preparation to learn		future
DiSessa and Wagner (2005)	reuse of knowledge demonstrated or acquired in one situation (or class of situations) in a new situation (or class of situations)	knowledge	reuse knowledge	one or class of situations	new
Royer et al. (2005)	"the complex and dynamic process leading to the activation and application of knowledge in response to context"	knowledge	activate and apply knowledge	context	
Rebello et al. (2005)	activation of tools (knowledge pieces) in source and target contexts	tools (knowledge pieces)	activate	in source and target contexts	
Helfenstein (2006) p72	relation and concordance between mental representations	mental representations	apperceive relation and concordance		

Researcher(s)	Definition/description	What is transferred	Actions of learners	Contexts (where and when)	Reference to similarity or difference
Cui et al. (2006)	"the ability to apply what has been learned in one context to a new context"	what has been learned	apply	context	One/ new
Marton (2006)	***generative*** learning as way of referring to how learning something in one situation makes you better at learning something else in another situation	learning something	become better at learning something else	situation	One/another Something (else)
Marton (2006)	Relations between what people learn and can do in different situations	What people learn	What people can do	situations	Difference in situations (also similarity)
Ohlsson (2011) p16	"process of applying a regularity from the past to future situations"	regularity	apply	situations	Regularity past to future
Chi and VanLehn (2012)	ability of individuals to treat a new concept, problem or phenomenon as similar to one(s) they have experienced before	ways of treating a concept, problem or phenomenon	treat in a particular way	experienced concept, problem or phenomenon	new similar before
(Perkins & Salomon, 2012)	Detect, elect, connect	Prior learning	detect, elect, connect		prior
Lobato (2012)	generalisation of learning or influence of a learners prior activities on activity in a novel situation	learning experience of prior activities	generalise, influence	Activities, situation	novel prior
Larsen-Freeman (2013)	conceive transfer in language learning as transformation of rather than export	language features	transform		

Researcher(s)	Definition/description	What is transferred	Actions of learners	Contexts (where and when)	Reference to similarity or difference
Leberman et al. (2016) p1	"transfer of learning occurs when prior-learned knowledge and skills affect the way in which new knowledge and skills are learned and performed"	knowledge and skills	affect new learning and performance		prior/ new
Hajian (2019)	"the productive application of prior learning and experiences in novel contexts"	prior learning and experiences	productive application	contexts	novel

Appendix C – A Range of Classifications of Transfer of Learning

Classification	Example papers	What is classified	Criteria	Divisions	Comments	Relevance to educators
Lateral and vertical	Gagne (1965)	Direction of transfer (3)	Deeper knowledge within a domain or wider knowledge extending to other domains	2 forms: • lateral • vertical		Directly applicable to educators work, especially in distinguishing enrichment from acceleration as forms of extension
Literal and figural	Royer (1979)	Transfer process (2)	Similarity of learning - intact or changed	2 types: • literal • figural	Figural relates to pieces of knowledge, including everyday knowledge as a tool for further learning	Royer points out that figural transfer plays a major role in misconceptions and is often underestimated by educators
Near and far	Royer (1979); expanded by Barnett and Ceci (2002)	Content (1) and contexts (3)	Degree of similarity	3 content: • Learned skill (procedure-representation-principle) • Performance change (speed-accuracy-approach) • Memory demands (execute only-recognise and execute-recall, recognise and execute) 6 context (near-far): • Knowledge domain • Physical context • Temporal context • Functional context	3 content categories are not clear cut, and a study would need to be very broad to cover all possibilities; 6 context categories are easy to apply as a gradient when comparing two or more instances but much harder to quantify	Useful in considering the discrepancy between what students demonstrate at the time of learning compared to at a later date, in formal assessment or in other contexts. Memory demands have relevance to describing the amount of cuing in tasks.

Classification	Example papers	What is classified	Criteria	Divisions	Comments	Relevance to educators
				• Social context • Modality		
Low and high road	Salomon and Perkins (1989)	Automaticity (2)	Effort, time	• Low road automatic transfer of well-rehearsed knowledge • High road – deliberate and effortful search for relevant information	Related to the distinction between novice (high road) and expert (low road) transfer	Distinguishes transfer of rote-learnt material from problem-solving
Problem classification	Gott, Parker Hall, Pokorny, Dibble and Glaser (1993)	Problems (2 and 3)	Similarity in contexts and solution procedures	Matrix of 4 types: • equivalent (same context; same procedure) • similar (same context; different procedure) • isomorphic (different contexts; same procedure) • unrelated (different contexts; different procedures)	Particular instance of near and far. Context similar to Barnett and Ceci, but content differs.	Useful in generating or evaluating transfer tasks
Coordination class	DiSessa (2002)	Components of the concept (1)	Level of sophistication	3 levels: • level 1 core function (what is it it for) • level 2 span (where does it work) and alignment what is common about where it works) • level 3 architecture (readout strategies,	Used by several researchers to interpret what students did transfer in transfer tasks	Potential to inform educators' analyses of transfer failures and successes

Classification	Example papers	What is classified	Criteria	Divisions	Comments	Relevance to educators
				causal net, processing)		
Specific and nonspecific	Royer et al. (2005)	Similarity between tasks (3)	similarity	2 types: • specific • nonspecific	Examples relate to early experiments in learning lists or paired words; gradient identifiable but quantification difficult	Covered by near and far if metacognitive aspects are included in learning
Transfer in and out	Schwartz et al. (2005)	Perspective (2)	Looking back at learning brought in or forward to ways learning may be used	2 types: • into situation (affects learning) • out from situation (affects performance)	Authors distinguish sequestered problem solving (SPS) from preparation for future learning (PFL)	Both of these learning scenarios are relevant to educators daily work and offer a potentially useful perspective on learning tasks
Fuzzy trace	Wolfe et al. (2005)	Memory system (1)	Kind of processing	2 types: • verbatim • gist	Distinction between memory for surface detail and memory for underlying patterns, which are processed differently	A simple dichotomy which enables educators to consider the demands of tasks including working memory and the resulting transfer
Transfer and assessment	Hickey 2005 Hickey, Taasoobshirazi and Cross (2012)	Assessment practice (3)	orientation of assessment in relation to model of learning	5 types: • immediate - artefacts of enacted learning () • close – semi-formal classroom assessment (activity-oriented; situated learning) • proximal - formal classroom assessment (curriculum oriented; representational learning)	Aligns different formative and summative functions of each kind of assessment	Immediately recognisable in current assessment practices and links assessment tasks to purpose; makes explicit the role of feedback in formative assessment

Classification	Example papers	What is classified	Criteria	Divisions	Comments	Relevance to educators
				• distal – criterion-referenced external tests (standards oriented; associationist learning) • remote – norm-referenced external tests (standards oriented, associationist learning)		
Dimensions of transfer	(DiSessa & Wagner, 2005)	Conditions of preparation (3)	Well, sufficiently or unprepared	3 Types: • class A: well prepared, short time • class B: sufficiently prepared, acceptable time (hours/days) with other resources • class C: unprepared, learning rather than transfer	Highlights the reliance of much research on class A transfer which fails when class B or C might have occurred	Raises the profile of class B and C transfer, which is much of what happens in classrooms
		Conditions of test (3)	Time allowed to demonstrate transfer			
Levels of transfer	Calais (2006) after Haskell (2004)	Combination of knowledge (1)and context (3)	Increasing specificity combined with degrees of similarity	6 levels: • nonspecific • application • context • near • far • creative	Haskell distinguishes between applying learning (not transfer) and learning something new (transfer)	A lengthy list of overlapping categories., many of them recognisable in classrooms but of limited practical use in designing or measuring learning
Kinds of transfer		Type of knowledge (1)		5 kinds: • declarative • procedural	Haskell admits they are difficult to separate and considers declarative to	

Classification	Example papers	What is classified	Criteria	Divisions	Comments	Relevance to educators
				• strategic • conditional • theoretical	be the most important for transfer.	
Kind and level of transfer		Type of knowledge and kind of transfer (1 and 2)	Combination of knowledge type with outcome	14 combinations of above • Content to content • Procedural to procedural • Declarative to procedural • Procedural to declarative • Strategic • Conditional • Theoretical • General or nonspecific • Literal • Vertical • lateral • reverse • proportional • relational	Haskell admits they are not mutually exclusive	
Transfer	Benander (2018)	What is transferred (1)		Knowledge • epistemic • procedural • disciplinary • interdisciplinary Skills • cognitive and metacognitive • social and emotional • physical and practical		

Classification	Example papers	What is classified	Criteria	Divisions	Comments	Relevance to educators
				Attitudes and values • personal • local • societal • human		

Appendix D – Examples of a Range of Models of Transfer of Learning

Model	Researcher(s)	Description
Formal disciplines Transfer is a generalisation of high-level cognitive skills to other relevant curriculum areas	Thorndike and Woodworth (1901)	Training in one skill/function (e.g. statistical thinking, logic, discrimination) can be applied more generally (e.g. to other curriculum areas)
Associationist Transfer is the recognition of identical elements in contexts which triggers the application of previous knowledge	Thorndike (1903)	Transfer occurs when learners recognise identical elements (metal habits)
Behaviourist Transfer is a response to a stimulus that has similarities with the same response to a past stimulus	Ellis (1965)	Combination of response integration and association hook
Cognitive Transfer is the application of knowledge to new contexts	Gick and Holyoak (1980) Gick and Holyoak (1983)	Transfer by analogy is the recognition of similar deep struct
	Holyoak and Thagard (1997)	Transfer of analogy involves mapping under three constrai similarity, structure and purpose
	Bransford and Schwartz (1999)	Transfer is preparation for future learning, interpretive rath than replicative or applicative
	DiSessa (2002)	P prims and coordination class to describe knowledge
	(Vermeulen, 2002)	Transfer is a continuous interchange between training and contexts separated by a membrane rather than a gap.
	Goldstone and Son (2005)	Transfer when concrete elements become idealised
	Wolfe et al. (2005)	Fuzzy trace theory. Transfer for verbatim and gist use separ systems, and transfer is a trade-off between the two.
	Rebello et al. (2005)	Transfer involves external inputs and the selection of tools construct an answer. It depends on whether the learner se knowledge as propagated or fabricated.
	Nokes (2009)	There are multiple mechanisms of transfer: analogy, knowl compilation and constraint violation, depending on the lea resources and environment. There is a trade-off between applicability and efficiency.
	Ohlsson (2011)	Transfer is backing up knowledge tree until rules work then cognitive work to apply them to a new context
	Chi and VanLehn (2012)	Transfer is identifying and acting on similarity in second-or relationships
	Levrini, Fantini, Tasquier, Pecori and Levin (2015)	Appropriation – transform scientific discourse to embody it one's personal story
Situated Transfer is the interaction	Lave (1988)	Learning is inextricably tied to context. Transfer is adding m contexts that share similarity

Model	Researcher(s)	Description
between the mental contents of learners and their social and environmental context	Gott et al. (1993)	Transfer is knowing, reasoning and understanding relations between cognitive agents and situations, shaped by social processes.
	Beach (1999)	Transfer is consequential transition – an ongoing relationsh between changing individuals and changing social contexts
	Hammer et al. (2005)	Transfer is activating mental resources in context
	Dufresne et al. (2005)	Transfer involves the coordination of knowledge pieces to r sense of a situation.
	Greeno (2006)	Contexts offer affordances to use knowledge that learners r take up
	Helfenstein and Saariluoma (2007)	Transfer is apperception – how people use their mental contents to interpret aspects of the context.
	Belland, Kim and Hannafin (2013)	Motivational goals of learners promote three kinds of engagement: behavioural, cognitive and affective. Transfer inextricably linked to these
	Jacot, Raemdonck and Frenay (2015)	Motivation influences engagement in both learning and tra stages
Learner focused/ Actor oriented Transfer is the existing learning brought to a situation	Kember, Biggs and Leung (2004)	Two dimensions of learning processes (motive and strategy position learners' orientations as surface, deep or achieving
	Lobato (2012)	Transfer is an expansion of experience
	Lobato et al. (2012)	Noticing explains transfer. A focusing framework of individu and social factors affect this
	Roorda et al. (2015)	Transfer is the personal construction of relationships betwe contexts.
Functional Transfer is whether or not people apply training in workplace scenarios, and the mechanism is treated as a black box.	Yelon (1992)	Four principles for promoting transfer of training Motivation Awareness Skill support
	Halpern (1998)	Four-part teaching model for teaching critical thinking to improve transfer across domains.
	Leimbach (2010)	Learner readiness • Motivation to learn • Intent to use • Career goal alignment • Self-efficacy Learning transfer design • Practice and modelling • Setting learning goals • Application review Organisational alignment • Manager support • Peer support • Job connection • Learning culture
	(Hajian, 2019)	Review of instructional practices • Problem based learning • Communities of practice

Model	Researcher(s)	Description
		• Cognitive apprenticeship – model, coach, fade • Game-based learning and simulations In the light of theories of transfer

Appendix E – Common Methods in Transfer of Learning Research

Features	Randomised controlled trials	Analysis of individual student thinking	Big data analysis	Quasi experimental design
Transfer view	Traditional	Expanded	Traditional	Combined – demonstration of learning outcomes
Time	Predominant methodology of 20th century	1990's and 21st-century	21st-century Except for Woodworth (1924)	21st-century
Question addressed	Did transfer occur?	What transfer occurred? How was it constructed?	What correlations are there between successful transfer and other demographic/ dispositional/ resourcing variables?	What is the effect of a particular classroom strategy?
Data	Quantitative	Qualitative	Quantitative	Qualitative and quantitative
Typical subjects	Undergraduate students participating for course credit or small cash payments	Individual and sometimes small groups of undergraduate and sometimes high school students participating as part of their course of study	School students participating in compulsory standardised testing programs	Classes of undergraduates and, more commonly, school students participatin as part of their course of study
Sample size	tens-hundreds	Usually less than 10	Hundreds – thousands+	Several class groups of 20-30
Design	Two problem design with a learning task and transfer task(s). Variables relate to learning and/or transfer	Qualitative data from task-based interview(s), teaching interview(s) and/or group problem solving	Test and survey response items	Evaluate teaching materials or program and compare those designed with strategies to promote transfer with usu

Features	Randomised controlled trials	Analysis of individual student thinking	Big data analysis	Quasi experimental design
	conditions. Some variations on this design	discussion		classroom methodologies
Measure	Whether targeted knowledge was transferred	Which parts and coordination of targeted knowledge was transferred. What other knowledge was transferred	Whether targeted knowledge was transferred	What parts and coordination of targete knowledge was transferred What other knowledge was transferrec
Analysis	Increasingly sophisticated correlation and factor analysis statistics	Patterns from records of learner discourse	Statistical correlation between transfer and demographic/ dispositional/ resourcing variables	Statistical comparison between what w transferred under different programs Patterns in learner responses and observed behaviour
Outcome	Variables that do and do not support transfer	How a range of variables affect the transfer process	Variables that do/do not correlate with transfer	To what degree combinations of variables supported transfer How other variables affect this
Examples	Hendrickson and Schroeder (1941) Gick and Holyoak (1983) Goldstone and Son (2005)	Dufresne et al. (2005) Thaden-Koch et al. (2006) Roorda et al. (2015)	Kornilova et al. (2009) Gee and Wong (2012) Gabriel et al. (2018)	Hackling (2008) Melo and Miranda (2015) (Bae & Lai, 2020)

Appendix F – Factors Affecting Transfer of Learning with Research Findings

These have been sorted by whether their findings reported a positive, negative of no impact on transfer of learning. The majority of studies relate to the learning experience and these have been further sorted by the strategies investigated. There are some factors relating to the learners themselves and a small number of studies relating to other factors.

Positive effect		Negative effect		No effect	
Factors associated with the learning experience – framing of the learning					
Expansive framing language "was doing"	Hart and Albarracín (2009)				
Expansive framing	Engle, Nguyen and Mendelson (2011)				
Factors associated with learning experience – learners actively construct meaning					
Productive struggle	Szekely (1950)	Pointing out analogy	Day and Goldstone (2011)	Direct explanation	Goldwater and Gentner (2015)
Generate own analogies	Gick and Holyoak (1980)			Instruction or discovery teaching	Chen (2010)
Processing solution failures	Gick and McGarry (1992)			Procedural instruction and trial and error	Phye (2001)
Near miss examples	Gick and Paterson (1992)			Hands on versus explicit teaching	Kruit et al. (2018)
Problem posing	Nikata and Shimada (2005)				
icap framework	Chi (2009)				
Explain and analogy cf reading	Nokes-Malach, Meade and Morrow (2012)				

Positive effect		Negative effect		No effect	
Invention	Belenky and Nokes-Malach (2012)				
Leveraging students reasoning skills	Richland et al. (2012)				
Worked examples better than problem solving	Kim (2013)				
Analogical comparison	Goldwater and Gentner (2015)				
Completion of concept map	(Montpetit-Tourangeau, Dyer, Hudon, Windsor, Charlin, Mamede, & van Gog, 2017)				
Metacognition and memorisation	(Wu et al., 2020) (Tzohar-Rozen & Kramarski, 2017)				
Factors associated with the learning experience – responding to misconceptions					
Misconceptions addressed by supporting students to reorganise knowledge structure	(Clark, D'Angelo, & Schleigh, 2011)				
Refutation of misconceptions	(Beker et al., 2019)				
Factors associated with learning experience – abstraction, generalisation and deep structure					
Structural features	(Holyoak & Koh, 1987)	Strategies not learnt at general level	(Marsh, 2007)		

Positive effect		Negative effect		No effect	
Directed comparisons of structure	(Catrambone & Holyoak, 1989)	Abstract learning leads to inert knowledge	(Son & Goldstone, 2009)		
Ability to generalise adaptor	(Antonietti & Gioletta, 1995)	Increasing contextualisation	(Day et al., 2015)		
Multiple contexts support far transfer	(Stark, Mandl et al. 1999)	concreteness	(Kaminski et al., 2013)		
Concrete start moving to abstract training	(Goldstone & Sakamoto, 2003) (Goldstone & Son, 2005) (McNeil & Fyfe, 2012) (Siler & Klahr, 2016) (Jaakkola & Veermans, 2018)	Seductive details	(Abercrombie et al., 2019)		
Variety in source problems	(Chen & Mo, 2004)	Surface similarity with novices	(Novick, 1988)		
Abstract domain representations	(Sloutsky, Kamininski, & Heckler, 2005) (Day et al., 2015) (Snoddy, 2018)				
Procedural knowledge and practice with high variability tasks	(Nokes & Ohlsson, 2005)				
Categorisation better than comparison	(Kurtz & Loewenstein, 2007)				

Positive effect		Negative effect		No effect	
Transformative experiences	(Heddy, Sinatra, Seli, Taasoobshirazi, & Mukhopadhyay, 2016; Pugh, Linnenbrink-Garcia, Koskey, Stewart, & Manzey, 2010)				
Structural similarities	(Day & Goldstone, 2011)				
Source analogy encoded as abstract rather than concrete	(Mandler & Orlich, 2013)				
Case comparisons	(Alfieri, Nokes-Malach, & Schunn, 2013)				
Decontextualisation and recontextualisation,	(Peters et al., 2015)				
Factors associated with the learning experience - learner agency and meta-cognition					
Testing/feedback	(Butler, 2010)			Self-assessment motivation	(Yan, Brown, Lee, & Qiu, 2020)
Metacognitive support	(Roll, Holmes, Day, & Bonn, 2012)				
Testing	(Bjork et al., 2014)				
Personal meaning, reflection	(Peters et al., 2015)				
Other factors associated with the learning experience					
Longer training	(Cooper & Sweller, 1987)	Similar training examples	(Brookes et al., 2011)	Concept mapping	(Stewart, 2011)

Positive effect		Negative effect		No effect	
Many explanations, monitor and amend	(Chi et al., 1989)	Video or touch screen compared to concrete materials	(Moser, Zimmermann, Dickerson, Grenell, Barr, & Gerhardstein, 2015)		
Rule and example training (far transfer)	(Fong, Krantz et al. 1986)	Science investigations	(Gee & Wong, 2012)		
Testing on high level items	(Jensen, McDaniel, Woodard, & Kummer, 2014)				
Whole task versus part task	(Lim, Reiser, & Olina, 2009)				
Small group learning	(Pai, Sears, & Maeda, 2015)				
Inquiry oriented programs without kits	(Slavin et al., 2012)				
Science epistemology integrate with personal experience	(Edmondson & Novak, 1993)				
Tracing geometry	(Du & Zhang, 2019)				
Collaborative better than individual learning	(Yang, Wang, Cheng, Liu, Liu, & Chan, 2016)				
Factors associated with the contexts of learning and transfer					
Near / far transfer	(Dinsmore, Baggetta, Doyle, & Loughlin, 2014)	Strong contextual details	(Bassok & Holyoak, 1989)		

Positive effect		Negative effect		No effect	
STEM to science but not vice versa	(Kelley, Capobianco, & Kaluf, 2015)	Differences between source and target problems	(Chen & Mo, 2004)		
		Interdisciplinarity - connections between learning areas	(Lleixà, González-Arévalo, & Braz-Vieira, 2016)		
Factors associated with the learners					
Mastery goals Performance in success	Grant and Dweck (2003)	Performance in failure	Grant and Dweck (2003)	Initial domain knowledge	(Alexander & Murphy, 1998)
Deep learning cluster	Braten and Olaussen (2005)	Entity theory of intelligence	King (2012)	Ability to verbalise analogy, direct participation	(Day & Goldstone, 2011)
Goals mastery	Dupeyrat and Mariné (2005)	Avoidance goals	Schwinger and Stiensmeier-Pelster (2011)		
Need for cognition	Heijne-Penninga, Kuks, Hofman and Cohen-Schotanus (2010)	Prior knowledge had negative impact with virtual tutoring system	Hautala, Baker, Keurulainen, Ronimus, Richardson and Cole (2018)		
Approach goals	Schwinger and Stiensmeier-Pelster (2011)				
Theory of school performance	Wang and Ng (2012)				
Deep approaches	May, Chung, Elliott and Fisher (2012)				
Mastery goals	Belenky and Nokes-Malach (2012)				

Positive effect		Negative effect		No effect	
Growth mindset complex	Dweck and Yeager (2019)				
Mastery goal classroom talk	Boden et al. (2020)				
Prior knowledge	Braithwaite and Goldstone (2015)				
Testing on high level items	(Jensen et al., 2014)				
Structural similarity with experts	(Novick, 1988)				
Relational SOLO on reading comprehension	(Ramburuth & Mladenovic, 2004)				
Other					
Teacher generalisation PD	(Shemwell, Chase, & Schwartz, 2015)				
Teacher goal structure	(Shim, Cho, & Wang, 2013)				
Interventions/ classroom programs					
Learn to think, motivation and transfer to other curriculum areas	(Hu et al., 2016)			Guided practice	(Purpura, Baroody, Eiland, & Reid, 2016)
Giving feedback	(Philippakos & MacArthur, 2016)			Preschool maths intervention – no long term effect	(Watts et al., 2017)
Contrasting cases; noticing	(Chase et al., 2019)			Training by graduated prompts had no effect on far transfer	(Resing, Bakker, Pronk, & Elliott, 2016) (Vogelaar & Resing, 2018)

Positive effect		Negative effect		No effect	
Executive functions	(Dias & Seabra, 2017)			Working memory training	(Melby-Lervag & Hulme, 2013)
analogous comparison	(Goldwater & Gentner, 2015)			Retrieval and peer instruction no diff on far transfer; retrieval better on near	(Zu, Munsell, & Rebello, 2019)
Hands on and explicit instruction	(Kruit et al., 2018)				
Worked examples better than problem solving due to decreased cognitive load	Kim (2013)				

Appendix G – Mapping Transfer of Learning

This section describes the development of the framework used to map student transfer in the field study.

Initially, student responses were grouped independently of any of the available frameworks, e.g. SOLO or DoK. The four categories described below cover the range of responses in increasing order approximation of the scientific perspective. By definition, those from Category 1 showed no evidence of other categories, but for the remainder, individual responses sometimes demonstrated two or more categories.

Categories of student responses to Adelaide earthquake task

Category	Perspective of response	Example
1	**No** evidence of **new thinking**	No response or variations on reproducing the given information from students skilled at playing the assessment game
2	**Alternative thread** Evidence of thinking about the concept using ideas from a relevant but not targeted conceptual thread	They might challenge the validity of aspects of the context or invoke other learning such as *act of God*, *mother nature*
3	**Relevant general knowledge** Evidence of thinking about the concept using everyday/ general knowledge ideas	These can be adaptive e.g. considering past history of earthquakes or fault lines, or maladaptive, e.g. relating earthquakes to weather or latitude
4	**Target science concept** Evidence of thinking about the concept using scientific ideas	These can also be adaptive, e.g. relating earthquakes to activity at the borders of tectonic plates, maladaptive or limiting, e.g. the idea that tectonic plates only occur in only part of the earth's surface or that stationary tectonic plates cause no earthquakes. Students may also invoke other related scientific ideas such as related geological phenomena (volcanoes, rift valleys), continental drift, or the mechanism of convection currents in a molten mantle.

Within each category, there were responses invoking adaptive learning and others invoking maladaptive learning (misconception, alternative conception or limited conceptions). Also within each category were responses at a range of levels, which could be described by SOLO framework. The expanded framework is shown in the table below.

Expanded categories of student responses to Adelaide earthquake task

SOLO Code	Evidence of thinking	Response	Example from earthquakes unit q1	% responses in prior knowledge	% responses in summative assessment
No new thinking					
Po	None	No relevant response – no response or no intelligible response		3%	0%
P1	Constructs a response from given information	Reproduces given information – rephrases the question or makes an assertion with no explanation	*I would say there is a 75% chance of an earthquake How do you know there's an earthquake?*	4%	3%
Alternative thread					
P2	relevant but not targeted conceptual thread	Invokes other learning related to the task but not the target conceptual thread	*It's just mother nature It depends how strong the buildings are*	36%	11%
General knowledge					
u'/m'/r'	Targeted conceptual thread using everyday but mal adaptive ideas	Invokes misconceptions[27] or limited conceptions about everyday thinking	*It's not likely because we are a bigger country*	0%	0%
u/m/r	Targeted conceptual thread using everyday adaptive ideas	Invokes everyday thinking	*It's not likely because we haven't had any big earthquakes here in the past*	23%	9%
Target science concept					
U'/M'/R'	targeted science conceptual thread but maladaptive ideas	Invokes misconceptions or limited conceptions about the science concept	*It's not likely because we don't have any plates here and they have lots over in New Zealand*	19%	22%
U	targeted science conceptual thread	One correct idea related to the science concept in this context	*We aren't on a border like New Zealand*	1%	0%

[27] Some researchers and educators prefer the term alternative conceptions or naive conceptions as from the perspective of the learner they are just as valid as the science conceptions are to experts. However, from the perspective of western science, they are maladaptive and therefore referred to as misconceptions in this work.

	consistent with western science				
M	targeted science conceptual thread consistent with western science	More than one separate idea related to the science concept in this context **or** Describes the link or rule without reference to the context[28]	*Unlikely because we aren't near the edge of our tectonic plate Earthquakes occur on the edges of tectonic plates*	11%	50%
R	targeted science conceptual thread consistent with western science	Describes the link between ideas	*Unlikely because we aren't on the edge of a tectonic plate where earthquakes occur more often*	1%	4%
EA	targeted science conceptual thread consistent with western science	Describes the context as an instance of a wider rule that applies to other contexts as well	*Earthquakes are more severe at the edges of tectonic plates where they collide with each other. Christchurch in New Zealand is on the edge of a plate and so gets large earthquakes but Adelaide is not and so our earthquakes are smaller*	2%	2%

This set of categories takes the idea of two levels from the work of Panizzon et al. (2006) and adds a dimension for maladaptive learning. It also expands the prestructural level to distinguish transfer of learning other than the targeted science. The extended abstract level was rare but useful in a handful of cases that went beyond the context of the question. These students are often not normally distinguished in classroom measures.

While a small number of science perspective responses clearly explained the link between plate boundaries and earthquakes, the vast majority simply linked a low probability of severe earthquakes with not being on plate boundaries. These were rated as R if it was clear that being on a plate

[28] Level reduction in SOLO

boundary was linked to earthquake probability and M if they simply stated that Adelaide was not on a plate boundary.

Because of difficulties in differentiating between some subcategories within the major categories, some subcategories were amalgamated to remove inconsistencies between scoring work samples. The final classification is shown in the following table.

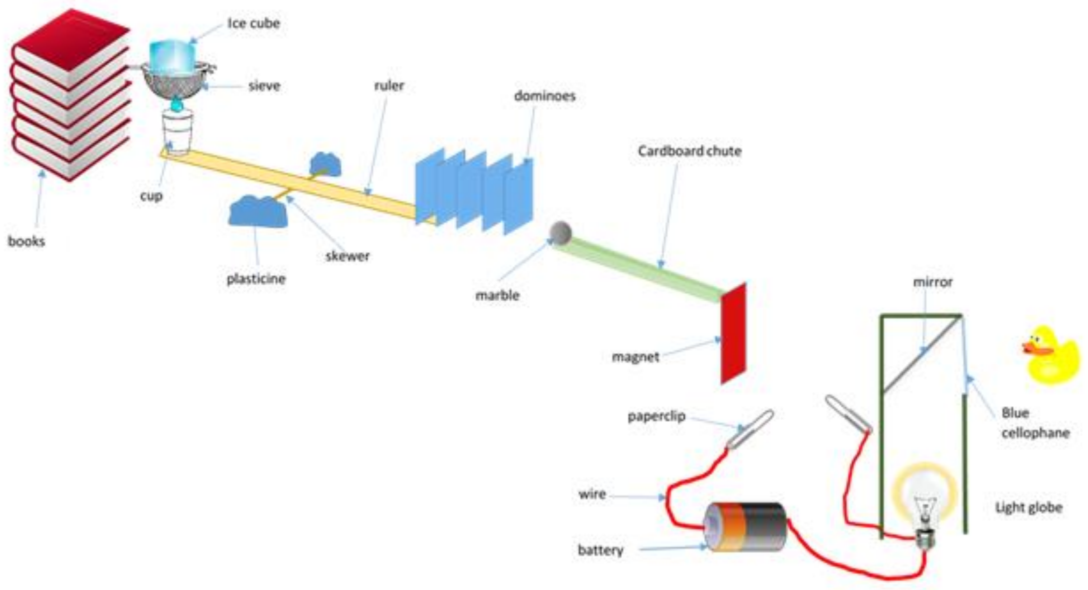
Final framework for classifying levels of transfer and frequency of responses in Unit 1.

Code	Evidence of thinking	Response	% responses in prior knowledge	% responses in summative assessment
NO	None	No new thinking – no response or reproduces given information	3%	0%
NN	Relevant but not targeting the conceptual thread	Invokes other learning related to the task but not the target conceptual thread	40%	14%
GL	Limited general knowledge	Either names, describes or relates misconceptions about a related general knowledge idea	0%	0%
GT	Sound general knowledge	General knowledge idea relevant to and consistent with the targeted science concept	23%	10%
SL	Limited knowledge about the science concept	Either names describes or misconceptions about a related general knowledge idea	20%	22%
ST	Sound knowledge of the science concept	Knowledge of parts of the targeted science concept and/or the connections between them	14%	55%

The framework was applied to classify student responses to the equivalent task in the second unit on the flow of electrical energy.

The second unit was on the flow of electrical energy, with the same sequence of lessons. This task is shown in the figure below.

This shows a plan for a chain reaction. It is designed to end by switching on an electric circuit.



Explain how the circuit part of the design would work.

Chain reaction task for electrical energy unit

While the generic descriptions of each level remain the same, examples of what these look like in the different context are shown in the table below.

Table 4 Examples of responses from electrical energy unit work samples

SOLO Code	Evidence of thinking	Response	Example from earthquakes unit q1.	Example from electrical energy unit q1.
No new thinking				
Po	None	No relevant response – no response or no intelligible response		*I don't know*
P1	Constructs a response from given information	Reproduces given information – rephrases the question or makes an assertion with no explanation	*I would say there is a 75% chance of an earthquake* *How do you know there's an earthquake?*	*The paperclip is attached to the battery which is attached to the light which is attached to a paperclip …*
Alternative thread				
P2	relevant but not targeted conceptual thread	Invokes other learning related to the task but not the target conceptual thread	*It's just mother nature* *It depends how strong the buildings are*	*It's a system that works when the ball starts rolling*
General knowledge				
u'/m'/r'	Targeted conceptual thread using everyday but mal adaptive ideas	Invokes misconceptions[29] or limited conceptions about everyday thinking	*It's not likely because we are a bigger country*	*The magnet has power which goes to the globe*
u/m/r	Targeted conceptual thread using everyday adaptive ideas	Invokes everyday thinking	*It's not likely because we haven't had any big earthquakes here in the past*	*Power from the battery lights the globe*
Target science concept				
U'/M'/R'	targeted science conceptual thread but maladaptive ideas	Invokes misconceptions or limited conceptions about the science concept	*It's not likely because we don't have any plates here and they have lots over in New Zealand*	*The battery is a conductor which allows energy from the magnet to go to the globe*
U	targeted science conceptual thread consistent with western science	One correct idea related to the science concept in this context	*We aren't on a border like New Zealand*	*One of:* *Energy comes from the battery* *Energy travels through wires* *The globe transforms it into light energy*

[29] Some researchers and educators prefer the term alternative conceptions or naive conceptions as from the learner's perspective they are as valid as the science conceptions are to experts. However, from the perspective of western science, they are maladaptive and therefore in this work referred to as misconceptions.

SOLO Code	Evidence of thinking	Response	Example from earthquakes unit q1.	Example from electrical energy unit q1.
M	targeted science conceptual thread consistent with western science	More than one separate idea related to the science concept in this context **or** Describes the link or rule without reference to the context[30]	*Unlikely because we aren't near the edge of our tectonic plate Earthquakes occur on the edges of tectonic plates*	*Several of: Energy comes from the battery Energy travels through wires The globe transforms it into light energy*
R	targeted science conceptual thread consistent with western science	Describes the link between ideas	*Unlikely because we aren't on the edge of a tectonic plate where earthquakes occur more often*	*The magnet falls and attracts the paperclip, completing the circuit and allowing energy from the battery to flow through the wires to the globe*
EA	targeted science conceptual thread consistent with western science	Describes the context as an instance of a wider rule that applies to other contexts as well	*Earthquakes are more severe at the edges of tectonic plates where they collide with each other. Christchurch in New Zealand is on the edge of a plate and so gets large earthquakes but Adelaide is not and so our earthquakes are smaller*	*This is a complete circuit because the magnet acts as a conductor so that energy from the battery can flow through the light globe where it is transformed into light*

The relative frequencies of these responses are shown in the table below.

[30] Level reduction in SOLO

Relative frequencies of responses in the electrical energy unit

Code	Evidence of thinking	Response	% responses in prior knowledge	% responses in summative assessment
NO	None	No new thinking – no response or reproduces given information	3%	0%
NN	Relevant but not targeting the conceptual thread	Invokes other learning related to the task but not the target conceptual thread	40%	14%
GL	Limited general knowledge	Either names, describes or relates misconceptions about a related general knowledge idea	0%	0%
GT	Sound general knowledge	General knowledge idea relevant to and consistent with the targeted science concept	23%	10%
SL	Limited knowledge about the science concept	Either names, describes or relates misconceptions about a related general knowledge idea	20%	22%
ST	Sound knowledge of the science concept	Knowledge of parts of the targeted science concept and/or the connections between them	14%	55%

In both units, some responses had evidence of thinking at a range of levels. These were scored at the level closest to the highest level of the science conceptual thread. The highest level of transfer demonstrated falls into one of three groups:

Exclusive in that it was the only level of transfer demonstrated. This accounted for over 90% of transfer in both the prior knowledge and summative assessment tasks in Unit 1;

Dominant in which other responses appeared to be afterthoughts;

Emergent in which this response appeared to be an afterthought.

The frequencies of responses in each of these categories for Units 1 and 2 are shown in the table below.

Classifying responses with more than one category of transfer

Dominance	Indicator	Frequency Unit 1 (pre/post tasks)	Frequency Unit 2 (pre/post tasks)
Exclusive	No other responses	93%/90%	91%/92%
Dominant	More than half of responses/ first response/ connectors indicating importance	4%/7%	1%/4%
Emergent	Less than half of responses/ later responses/ connectors indicating less importance	3%/3%	8%/4%

The number of students with responses at multiple levels was low in both pre and post-test and in both units. Multiple responses were greatest when the dominant responses were in the lower levels of the science conceptual thread (U and M), possibly because learners did not trust the newer knowledge enough to abandon their everyday thinking. Students who had R and EA level responses rarely included general knowledge conceptual threads in their responses.

The framework allows classification of the range of learning transferred in both the pre-test and post-test versions of the tasks in the two units. It distinguishes between misconceptions and adaptive learning of the science concept, between irrelevant, everyday and science conceptual threads and within a thread between thinking at different levels. It not only provides a snapshot of learners thinking (albeit through the proxy of task work sample) but the potential to track the thinking of individual learners through the sequence of learning tasks.

Appendix H – Ethics Approval for *Transfer in Classroom Tasks* Study

FINAL APPROVAL NOTICE

Project No.:	**7499**
Project Title:	Transfer of science concepts R-7
Principal Researcher:	Ms Anne Pillman
Email:	pill0056@flinders.edu.au
Approval Date:	8 February 2017
Ethics Approval Expiry Date:	**1 February 2022**

The above proposed project has been **approved** on the basis of the information contained in the application, its attachments and the information subsequently provided with the addition of the following comment(s):

Additional information required following commencement of research:

1. Permissions
   Please ensure that copies of the correspondence granting permission to conduct the research from the Principal, Westbourne Park primary school are submitted to the Committee *on receipt.* Please ensure that the SBREC project number is included in the subject line of any permission emails forwarded to the Committee. Please note that data collection should not commence until the researcher has received the relevant permissions (item D8 and Conditional approval response – number 3).

2. Other Ethics Committees
   Please provide a copy of the ethics approval notice from DECD *on receipt*. Please note that data collection should not commence until the researcher has received the relevant ethics committee approvals (item G1 and Conditional approval response – number 4).

RESPONSIBILITIES OF RESEARCHERS AND SUPERVISORS

1. Participant Documentation

Please note that it is the responsibility of researchers and supervisors, in the case of student projects, to ensure that:

- all participant documents are checked for spelling, grammatical, numbering and formatting errors. The Committee does not accept any responsibility for the above mentioned errors.

- the Flinders University logo is included on all participant documentation (e.g., letters of Introduction, information Sheets, consent forms, debriefing information and questionnaires – with the exception of purchased research tools) and the current Flinders University letterhead is included in the header of all letters of introduction. The Flinders University international logo/letterhead should be used and documentation should contain international dialling codes for all telephone and fax numbers listed for all research to be conducted overseas.

- the SBREC contact details, listed below, are included in the footer of all letters of introduction and information sheets.

This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee (Project Number 'INSERT PROJECT No. here following approval'). For more information regarding ethical approval of the project the Executive Officer of the Committee can be contacted by telephone on 8201 3116, by fax on 8201 2035 or by email human.researchethics@flinders.edu.au.

2. Annual Progress / Final Reports

In order to comply with the monitoring requirements of the *National Statement on Ethical Conduct in Human Research (March 2007)* an annual progress report must be submitted each year on the **8 February** (approval anniversary date) for the duration of the ethics approval using the report template available from the Managing Your Ethics ApprovalSBREC web page. *Please retain this notice for reference when completing annual progress or final reports.*

If the project is completed *before* ethics approval has expired please ensure a final report is submitted immediately. If ethics approval for your project expires please submit either (1) a final report; or (2) an extension of time request andan annual report.

Student Projects

The SBREC recommends that current ethics approval is maintained until a student's thesis has been submitted, reviewed and approved. This is to protect the student in the event that reviewers recommend some changes that may include the collection of additional participant data.

Your first report is due on **8 February 2018** or on completion of the project, whichever is the earliest.

3. Modifications to Project

Modifications to the project must not proceed until approval has been obtained from the Ethics Committee. Such proposed changes / modifications include:

- change of project title;
- change to research team (e.g., additions, removals, principal researcher or supervisor change);
- changes to research objectives;
- changes to research protocol;
- changes to participant recruitment methods;
- changes / additions to source(s) of participants;
- changes of procedures used to seek informed consent;
- changes to reimbursements provided to participants;
- changes / additions to information and/or documentation to be provided to potential participants;
- changes to research tools (e.g., questionnaire, interview questions, focus group questions);

•extensions of time.

To notify the Committee of any proposed modifications to the project please complete and submit the *Modification Request Form* which is available from the Managing Your Ethics Approval SBREC web page. Download the form from the website every time a new modification request is submitted to ensure that the most recent form is used. Please note that extension of time requests should be submitted prior to the Ethics Approval Expiry Date listed on this notice.

Change of Contact Details

Please ensure that you notify the Committee if either your mailing or email address changes to ensure that correspondence relating to this project can be sent to you. A modification request is not required to change your contact details.

4. Adverse Events and/or Complaints

Researchers should advise the Executive Officer of the Ethics Committee on 08 8201-3116 orhuman.researchethics@flinders.edu.au immediately if:

•any complaints regarding the research are received;
•a serious or unexpected adverse event occurs that effects participants;
•an unforeseen event occurs that may affect the ethical acceptability of the project.

Appendix I – Australian Curriculum Chemical Sciences for classroom task

	Science literacy progress map	Year Level Description	Content Description	Achievement Standard	Achievement standard n candle context
F	Describes or recognises one aspect or property of an individual o0bject of event that has been experienced or reported (concrete unistructural)	Observe and describe the behaviour and properties of everyday objects and materials	Objects are made of **materials which have properties**	**Describe the properties and behaviours** of familiar objects	**Describes** property or behaviour of candle
1		Infer cause and effect,; observe the properties of	Ed materials can be **physically changed**	**Describe** objects and **effects of interacting** with objects and materials	Describes several properties or behaviour of candle materials
2		Describe components of simple systems e.g. how materials interact through manipulation	Different materials can be **combined for a purpose**	**Describe changes** to materials	Describes changes to property or behaviour of candle materials
3	**Describes changes to or differences** between properties of objects or events that have been experienced or reported (concrete multistructural)	Observe heat and its effect on solids and liquids	**Change of state** (solid to liquid) caused by **heat**	Use understanding of behaviour of heat to **suggest explanations**	Links the changes in the candle to heat
4		Broaden classification and form and function of properties of materials	Natural and processed materials have **physical properties that influence their use**	Apply **properties of materials** to **explain uses**	Links properties of candle materials to use
5	**Describes relationships** between individual events (including cause and effect) that have been experienced or reported. Can **generalise and apply** the rule by predicting future events (concrete relational)	Broaden classification of matter to include gases	Solids, liquids and **gases** have different properties and behaviour	**Classify** substances according to **properties and behaviour**	Uses properties of gases to identify one in in candle burning
6		Explore how changes can be classified	Changes to materials can be **reversible or irreversible**	**Compare and classify changes**	Distinguishes physical and chemical changes as candle burns and explains implications for reversing

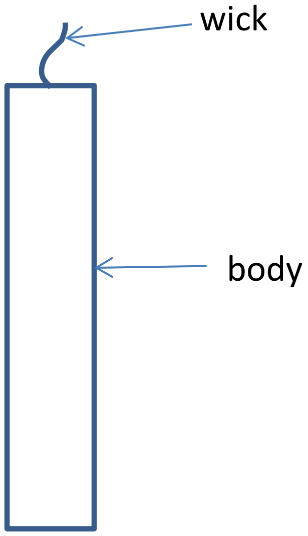
7	**Explains interactions, processes or effects** that have been experienced or reported in terms of a non-observable property or abstract science concept (abstract unistructural)		**Mixtures** contain a combination of substances and can be **separated**	**Describe techniques to separate pure substances from mixtures**	Links separation techniques to properties of candle materials

Appendix J – Student Record Sheets for Candle Task

Candle task observation and explanation worksheets

A candle (F)

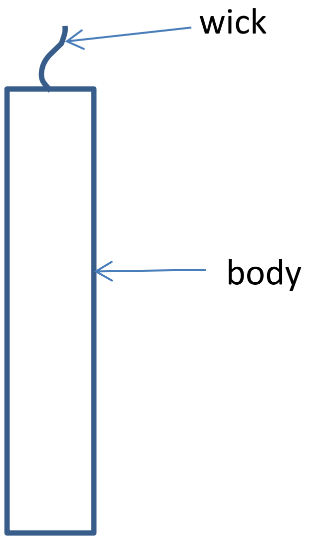
Add words to describe the parts.



Draw another diagram of the candle showing how it changes when it burns

A candle (Y1)

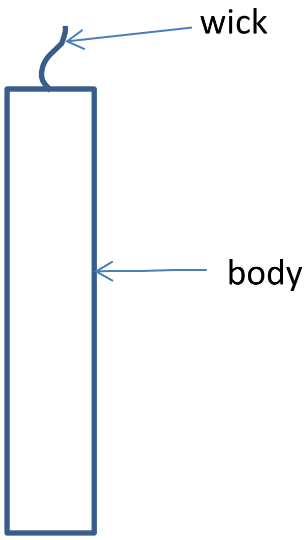
Add words to describe the parts.



Draw another diagram of the candle showing how it changes when it burns

A candle (Y2)

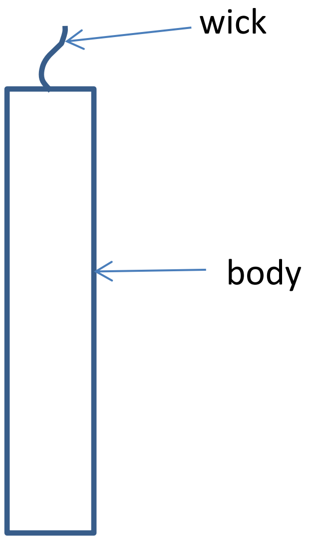
Add words to explain what the parts are for.



Draw another diagram of the candle showing how it changes when it burns

A candle (Y3)

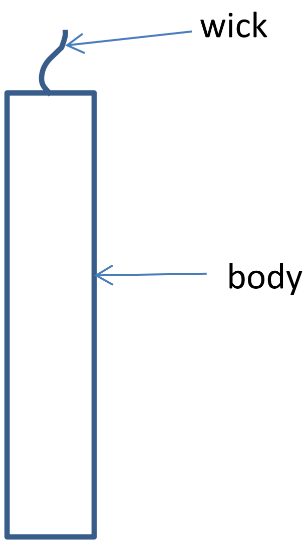
Add annotations (explanations) to give more information about the parts.



Draw a second annotated diagram to show how the candle changes as it burns. Are there any solids and liquids? How do you know?

A candle (Y4)

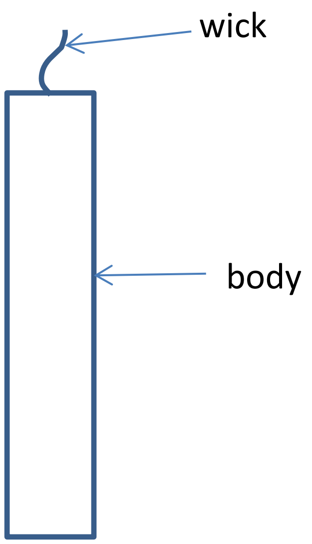
Add annotations to explain what each is made of and what makes it suitable. What else could that material be used for? What would make it suitable?



Draw a second annotated diagram to show how candle changes as it burns. Are there any solids and liquids? How do you know?

A candle (Y5)

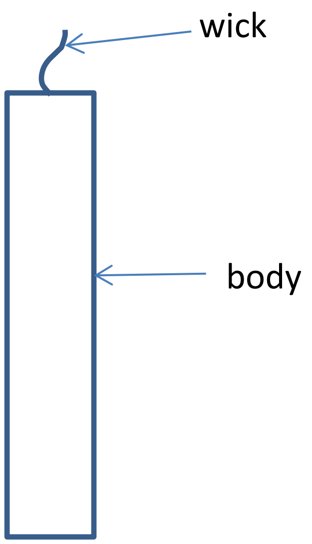
Add annotations to the diagram of a candle to give more information about the parts.



Draw a second annotated diagram of the candle showing how it changes when it has been burning for a while. How are solids, liquids and gases involved?

A candle (Y6)

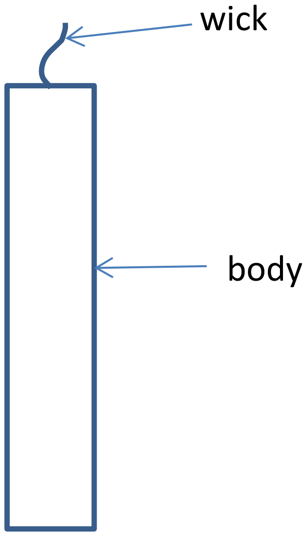
Add annotations to explain what each is made of and what makes it suitable. What else could that material be used for? What would make it suitable?



Draw a second annotated diagram of the candle showing how it changes when it has been burning for a while. Which changes can be reversed? Which can't?

A candle (Y7)

Add annotations to the diagram of a candle to give more information about the parts. How could you separate the wick from the wax? Explain how this works? How else?



Draw a second annotated diagram of the candle showing how it changes when it has been burning for a while. Which changes can be reversed? Which can't?

Candle task – *Explain with example* questions

F	
1	Choose one of these and explain what it means. Use an example to help. a) Things are made of materials b) Sometimes materials change c) Materials may change in different ways
2	Choose one of these and explain what it means. Use an example to help. a) Things are made of different materials b) Sometimes materials are mixed together d) Mixing materials can make them more useful
3	Choose **one** of these and explain what it means. Use an example to help. a) When something melts it gets runny b) Sometimes solids melt to become liquids c) Heat can cause materials to change between solid and liquid e) A material which has melted can be changed back.
4	Choose **one** of these and explain what it means. Use an example to help. a) Things are made of different materials b) Different materials have different properties f) How we use materials depends on their properties
5	Choose **one** of these and explain what it means. Use an example to help. a) Gases are invisible b) Gases spread through the air c) Gases have no shape or size g) In gases the particles are fast moving and a long way apart from each other
6	Choose **one** of these and explain what it means. Use an example to help. c) Chemical changes happen when chemicals are mixed d) Chemical change is the opposite of a physical change e) In chemical changes new substances are produced h) In chemical changes atoms are rearranged.
7	Choose **one** of these and explain what it means. Use an example to help. a) A mixture is a combination of 2 or more pure substances b) Some mixtures can be separated by filtering c) Mixtures can be separated using the different properties of the materials in the mixture i) A pure substance cannot be separated into different substances

Appendix K – Year 5 Student Responses to Candle Task Observation and Explanation

Year 5: describe solids, , liquids and gases in a burning candle								
No.	NO	NR	GL	GT	SL	ST1	ST2	ST3
1			*Wax … melt*		*Fire/ gas*			
2				*Liquid wax takes shape of object it is in which is itself*	*Flame - gas*			
3				*Liquid wax takes shape of object it is in which is itself*	*Flame - gas*			
4				*Wax melts into a liquid*	*Smoke … goes everywhere*			
5				*Wax turns into liquid*	*Fire is the gas*			
6				*Liquid wax because its shiny*		*Smoke – gases*	*Because it smells*	
7				*… it's melting and has some liquid*				
8				*… it's melting and has some liquid*	*It smells like smoke*			
9				*Wax has melted and become liquid*		*Wick has a gas come off*		
10	Unlabelled diagram only							

11						*The smoke is a gas*			
12			*The wax started melting*			*Smoke (gas) came off*			
13				*The wax melted … liquid*		*Smoke GAS*			
14				*Melts … and turns into a liquid*		*Flame goes into a gas also known as smoke*			
15			*Wax melted down*			*Gas from flame*			
16			*Wax melting*				*Gas from flame evaporating*		
17				*Wax turns into a liquid … its running down the side*		*Flame turns into a gas and goes to smoke*			
18			*Melting wax*						
19		Observed changes							
20				*There is liquid just on the top*					
21		Observed changes							
22						*Gas it* [sic] *and the smoke*			
23				*Wax is turning into a liquid*	*Gas=fire*	*Gas=smoke*			
24				*Liquid from wax*		Gases labelled to side of flame			
25				*Wax (liquid)*		*Gases - smoke*			

Appendix L – Year 5 Student Responses to *Explain with example* Task

Year 5: statement explanation									
Student No.	Statement choice	NO	NR	GL	GT	SL	ST1	ST2	ST3
1	B					*Smoke goes up*	*Air which is a gas*		
2	A		*particle s are spread apart*			*Fire and water vapour aren't invisible*			
3	A		*particle s are spread apart*						
4	C		*Gas particle s spread far apart*						*gases don't have a shape because they can go in any directio n*
5	C						*e.g. oxygen*		*Gases spread into many differen t shapes when its in the air*
6	D		*It spreads all over*					*You can smell from the other side of the room*	
7	C							*They float anywhe re and can fit in anythin g. They can fit*	

Year 5: statement explanation									
Student No.	Statement choice	NO	NR	GL	GT	SL	ST1	ST2	ST3
								into an enclosed shape and still move around	
8	C							*… floats everywhere and always moves around even in an enclosed place like a container. It moves around wherever you put it*	
9	B							*It goes through the air and spans out. It then keeps* on *going up into the atmosphere*	
10	C		*It can travel through the air*						
11	C		*Keeps on spreading through the air*			*Gas get either bigger or smaller*		*Doesn't stop* [spreading]*after a while*	
12	C		*Spreads through the air*	*Gases are everyw*					

Year 5: statement explanation									
Student No.	Statement choice	NO	NR	GL	GT	SL	ST1	ST2	ST3
			really fast	*here*					
13	D	*D ….The video showed how the particle s work*						*Air is always moving so the gas just can't stay still*	
14	C							*Air is always moving so the gas just can't stay still*	
15	A		*Can't see gases*						
16	D					*gases not trapped inside somethi ng like solids*			
17	C					*Fire goes bigger and doesn't stay in one shape*			
18	A	*I choose a*							
19	B						*air is a gas*	*Air … floats*	
20	B			air is everyw here				*smoke spreads through the air air expands through the world everyw here*	
21	B		*air … and if it*				*air is a gas*		

Year 5: statement explanation									
Student No.	Statement choice	NO	NR	GL	GT	SL	ST1	ST2	ST3
			does not spread						
22	A			*Air is the most popular gas in the world*			*air is a gas and is invisible smoke is a gas*		
23	A			*Air is the most popular gas in the world*			*air is a gas*		
24	C								*Smoke … moves out … without a definite shape*
25	C					*Smoke disappears after a couple of seconds*		*smoke … moves as much as it wants and goes anywhere*	

Appendix M – Pilot Study Classroom Program

Year 5 teaching materials available in supplementary folder

Appendix N – Ethics Approval for Pilot Study

FINAL APPROVAL NOTICE

Project No.:	**6892**
Project Title:	Factors affecting transfer of science learning - task field trial
Principal Researcher:	Ms Anne Pillman
Email:	pill0056@flinders.edu.au
Approval Date:	10 August 2015
Ethics Approval Expiry Date:	**30 December 2020**

The above proposed project has been **approved** on the basis of the information contained in the application, its attachments and the information subsequently provided with the addition of the following comment(s):

Additional information required following commencement of research:

1. Permissions
   Please ensure that copies of the correspondence granting permission to conduct the research from the principals of all schools to be involved are submitted to the Committee *on receipt.* Please ensure that the SBREC project number is included in the subject line of any permission emails forwarded to the Committee. Please note that data collection should not commence until the researcher has received the relevant permissions (item D8 and Conditional approval response – number 8).
2. Other Ethics Committees
   Please provide a copy of the ethics approval notice from the Department of Education and Child Development (DECD) *on receipt*. Please note that data collection should not commence until the researcher has received the relevant ethics committee approvals (item G1 and Conditional approval response – number 11).

RESPONSIBILITIES OF RESEARCHERS AND SUPERVISORS

1. Participant Documentation

Please note that it is the responsibility of researchers and supervisors, in the case of student projects, to ensure that:

- all participant documents are checked for spelling, grammatical, numbering and formatting errors. The Committee does not accept any responsibility for the above mentioned errors.
- the Flinders University logo is included on all participant documentation (e.g., letters of Introduction, information Sheets, consent forms, debriefing information and questionnaires – with the exception of purchased research tools) and the current Flinders University letterhead is included in the header of all letters of introduction. The Flinders University international logo/letterhead should be used and

documentation should contain international dialling codes for all telephone and fax numbers listed for all research to be conducted overseas.

- the SBREC contact details, listed below, are included in the footer of all letters of introduction and information sheets.

This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee (Project Number 'INSERT PROJECT No. here following approval'). For more information regarding ethical approval of the project the Executive Officer of the Committee can be contacted by telephone on 8201 3116, by fax on 8201 2035 or by email human.researchethics@flinders.edu.au.

2. Annual Progress / Final Reports

In order to comply with the monitoring requirements of the *National Statement on Ethical Conduct in Human Research (March 2007)* an annual progress report must be submitted each year on the **10 August** (approval anniversary date) for the duration of the ethics approval using the report template available from the Managing Your Ethics Approval SBREC web page. *Please retain this notice for reference when completing annual progress or final reports.*

If the project is completed *before* ethics approval has expired please ensure a final report is submitted immediately. If ethics approval for your project expires please submit either (1) a final report; or (2) an extension of time request and an annual report.

Student Projects

The SBREC recommends that current ethics approval is maintained until a student's thesis has been submitted, reviewed and approved. This is to protect the student in the event that reviewers recommend some changes that may include the collection of additional participant data.

Your first report is due on **10 August 2016** or on completion of the project, whichever is the earliest.

3. Modifications to Project

Modifications to the project must not proceed until approval has been obtained from the Ethics Committee. Such proposed changes / modifications include:

- change of project title;
- change to research team (e.g., additions, removals, principal researcher or supervisor change);
- changes to research objectives;
- changes to research protocol;
- changes to participant recruitment methods;
- changes / additions to source(s) of participants;
- changes of procedures used to seek informed consent;
- changes to reimbursements provided to participants;
- changes / additions to information and/or documentation to be provided to potential participants;
- changes to research tools (e.g., questionnaire, interview questions, focus group questions);
- extensions of time.

To notify the Committee of any proposed modifications to the project please complete and submit the *Modification Request Form* which is available from the Managing Your Ethics Approval SBREC web page. Download the form from the website every time a new modification request is submitted to ensure that the most recent form is used. Please note that extension of time requests should be submitted prior to the Ethics Approval Expiry Date listed on this notice.

Change of Contact Details

Please ensure that you notify the Committee if either your mailing or email address changes to ensure that correspondence relating to this project can be sent to you. A modification request is not required to change your contact details.

4. Adverse Events and/or Complaints

Researchers should advise the Executive Officer of the Ethics Committee on 08 8201-3116 or human.researchethics@flinders.edu.au immediately if:

- any complaints regarding the research are received;
- a serious or unexpected adverse event occurs that effects participants;
- an unforeseen event occurs that may affect the ethical acceptability of the project.

Appendix O - Pilot Study ANOVA Results

Carried out by Dr David Jeffries, Research Fellow, Education Policy and Practice, Australian Council for Educational Research

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
task 5a	Between Groups	.028	2	.014	.286	.752
	Within Groups	3.772	77	.049		
	Total	3.800	79			
task 5c	Between Groups	.076	2	.038	.211	.810
	Within Groups	13.874	77	.180		
	Total	13.950	79			
task 5d	Between Groups	.788	2	.394	4.854	.011
	Within Groups	5.522	68	.081		
	Total	6.310	70			

Multiple Comparisons

Games-Howell

Dependent Variable	(I) class	(J) class	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
task 5a	1	2	-.003	.052	.998	-.13	.12
		3	-.041	.064	.798	-.20	.11
	2	1	.003	.052	.998	-.12	.13
		3	-.038	.066	.829	-.20	.12
	3	1	.041	.064	.798	-.11	.20
		2	.038	.066	.829	-.12	.20
task 5c	1	2	.007	.112	.998	-.26	.28

		3	-.062	.117	.856	-.35	.22
	2	1	-.007	.112	.998	-.28	.26
		3	-.069	.121	.834	-.36	.22
	3	1	.062	.117	.856	-.22	.35
		2	.069	.121	.834	-.22	.36
task 5d	1	2	.038	.038	.584	-.06	.13
		3	-.202	.095	.102	-.44	.03
	2	1	-.038	.038	.584	-.13	.06
		3	-.240*	.087	.029	-.46	-.02
	3	1	.202	.095	.102	-.03	.44
		2	.240*	.087	.029	.02	.46

*. The mean difference is significant at the 0.05 level.

Appendix P – Classroom Materials for Field Study

Year 7 classroom materials available in supplementary folder

Appendix Q – Ethics Approval for Field Study

FINAL APPROVAL NOTICE

Project No.:	**7582**
Project Title:	Factors affecting transfer of science learning - field trial
Principal Researcher:	Ms Anne Pillman
Email:	pill0056@flinders.edu.au

Approval Date:	4 April 2017	Ethics Approval Expiry Date:	**30 December 2021**

The above proposed project has been **approved** on the basis of the information contained in the application, its attachments and the information subsequently provided with the addition of the following comment(s):

Additional Comments

1. Child Assent Form

The Chairperson advises that the SBREC asks for a separate assent form in this age range as it relates to finding ways to reduce 'coercion' on the young person to participate; either from a teacher or a parent. Given that this research is low risk, and will involve regular teaching activities, the Chairperson is prepared to accept the countersigning on the parent / guardian Consent Form; provided that the form contains a reference to '*I have explained this study to my child'.* In this way the parent / guardian can pitch it in a way that best suits their child.

Workload for collecting papers is not a concern of the SBREC and this argument would not be persuasive as we are focused on ethical dimensions.

2. Permissions

Please ensure that copies of the correspondence granting permission to conduct the research from principals of all the schools to be involved are submitted to the Committee *on receipt.* Please ensure that the SBREC project number is included in the subject line of any permission emails forwarded to the Committee. Please note that data collection should not commence until the researcher has received the relevant permissions (item D8 and Conditional approval response – number 14).

3. Permissions

The committee notes that the letter and Information Sheet for principals has been rewritten which is fine. Please just ensure that when principals reply via email that they state clearly what they are happy to provide permission for (not consent) (item D8 and Conditional approval response – number 14).

4. Other Ethics Committees

Please provide a copy of the ethics approval notice from the DECD *on receipt*. Please note that data collection should not commence until the researcher has received the relevant ethics committee approvals (item G1 and Conditional approval response – number 15).

RESPONSIBILITIES OF RESEARCHERS AND SUPERVISORS

1. Participant Documentation

Please note that it is the responsibility of researchers and supervisors, in the case of student projects, to ensure that:

- all participant documents are checked for spelling, grammatical, numbering and formatting errors. The Committee does not accept any responsibility for the above mentioned errors.
- the Flinders University logo is included on all participant documentation (e.g., letters of Introduction, information Sheets, consent forms, debriefing information and questionnaires – with the exception of purchased research tools) and the current Flinders University letterhead is included in the header of all letters of introduction. The Flinders University international logo/letterhead should be used and documentation should contain international dialling codes for all telephone and fax numbers listed for all research to be conducted overseas.
- the SBREC contact details, listed below, are included in the footer of all letters of introduction and information sheets.

This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee (Project Number 'INSERT PROJECT No. here following approval'). For more information regarding ethical approval of the project the Executive Officer of the Committee can be contacted by telephone on 8201 3116, by fax on 8201 2035 or by email human.researchethics@flinders.edu.au.

2. Annual Progress / Final Reports

In order to comply with the monitoring requirements of the *National Statement on Ethical Conduct in Human Research (March 2007)* an annual progress report must be submitted each year on the **4 April** (approval anniversary date) for the duration of the ethics approval using the report template available from the Managing Your Ethics Approval SBREC web page. *Please retain this notice for reference when completing annual progress or final reports.*

If the project is completed *before* ethics approval has expired please ensure a final report is submitted immediately. If ethics approval for your project expires please submit either (1) a final report; or (2) an extension of time request and an annual report.

Student Projects

The SBREC recommends that current ethics approval is maintained until a student's thesis has been submitted, reviewed and approved. This is to protect the student in the event that reviewers recommend some changes that may include the collection of additional participant data.

Your first report is due on **4 April 2018** or on completion of the project, whichever is the earliest.

3. Modifications to Project

Modifications to the project must not proceed until approval has been obtained from the Ethics Committee. Such proposed changes / modifications include:

- change of project title;
- change to research team (e.g., additions, removals, principal researcher or supervisor change);
- changes to research objectives;
- changes to research protocol;
- changes to participant recruitment methods;
- changes / additions to source(s) of participants;
- changes of procedures used to seek informed consent;
- changes to reimbursements provided to participants;
- changes / additions to information and/or documentation to be provided to potential participants;
- changes to research tools (e.g., questionnaire, interview questions, focus group questions);
- extensions of time.

To notify the Committee of any proposed modifications to the project please complete and submit the *Modification Request Form* which is available from the Managing Your Ethics Approval SBREC web page. Download the form from the website every time a new modification request is submitted to ensure that the most recent form is used. Please note that extension of time requests should be submitted prior to the Ethics Approval Expiry Date listed on this notice.

Change of Contact Details

Please ensure that you notify the Committee if either your mailing or email address changes to ensure that correspondence relating to this project can be sent to you. A modification request is not required to change your contact details.

4. Adverse Events and/or Complaints

Researchers should advise the Executive Officer of the Ethics Committee on 08 8201-3116 or human.researchethics@flinders.edu.au immediately if:

- any complaints regarding the research are received;
- a serious or unexpected adverse event occurs that effects participants;
- an unforeseen event occurs that may affect the ethical acceptability of the project.

Appendix R – Field Study ANCOVA Results

Carried out by Dr David Jeffries, Research Fellow, Education Policy and Practice, Australian Council for Educational Research

UNIT 1

Tests of Between-Subjects Effects

Dependent Variable: Unit1Post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1.528[a]	2	.764	3.199	.043	.038
Intercept	41.188	1	41.188	172.501	.000	.517
Unit1Pre	.746	1	.746	3.126	.079	.019
UnitCombo	.912	1	.912	3.821	.052	.023
Error	38.442	161	.239			
Total	95.000	164				
Corrected Total	39.970	163				

a. R Squared = .038 (Adjusted R Squared = .026)

UNIT 2

Tests of Between-Subjects Effects

Dependent Variable: Unit2Post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.209[a]	2	.105	.669	.514	.009
Intercept	5.634	1	5.634	36.062	.000	.190
Unit2Pre	0.000E+0	1	0.000E+0	.000	.989	.000
UnitCombo	.205	1	.205	1.315	.253	.008
Error	24.058	154	.156			
Total	30.000	157				
Corrected Total	24.268	156				

a. R Squared = .009 (Adjusted R Squared = -.004)

Bibliography for Appendices

Abercrombie, S. (2013). Transfer effects of adding seductive details to case-based instruction. *Contemporary Educational Psychology, 38*(2), 149-157. https://doi.org/http://dx.doi.org/10.1016/j.cedpsych.2013.01.002

Abercrombie, S., Hushman, C. J., & Carbonneau, K. J. (2019). The impact of seductive details and signaling on analogical transfer. *Applied Cognitive Psychology, 33*(1), 38-47. https://doi.org/10.1002/acp.3475

ACARA. (2021a). *Australian curriculum*. ACARA. https://www.australiancurriculum.edu.au/about-the-australian-curriculum/

ACARA. (2021b). *National assessment program*. Australian Curriculum, Assessment and Reporting Authority. https://www.nap.edu.au/

ACER. (2013). *Tests of reading comprehension teacher manual*.Melbourne, Australia: Australian Council for Educational Research.

Alexander, P. A., & Murphy, P. K. (1998). Profiling the differences in students' knowledge, interest, and strategic processing. *Journal of Educational Psychology, 90*(3), 435-447.

Alexander, P. A., & Murphy, P. K. (1999). Nurturing the seeds of transfer: a domain-specific perspective. *International Journal of Educational Research, 31*(7), 561-576. https://doi.org/http://dx.doi.org/10.1016/S0883-0355(99)00024-5

Alfieri, L., Nokes-Malach, T. J., & Schunn, C. D. (2013). Learning through case comparisons: a meta-analytic review. *Educational Psychologist, 48*(2), 87-113. https://doi.org/10.1080/00461520.2013.775712

Anderson, G. L., Krathwohl, D.R., Airasian, P.W., Cruikshank, K.A., Mayer, R.E., Printich, P.R. et als (Eds). (2001). *A taxonomy for learning, teaching and assessing: a revision of Bloom's taxonomy of educationla objectives.*Boston: Allyn & Bacon.

Anderson, J. R., Reder, L. M., & Simon, H. A. (1996). Situated learning and education. *Educational Researcher, 25*(4), 5-11. https://doi.org/10.3102/0013189x025004005

Anderson, R. J., Dewhurst, S., A, & Nash, R., A. (2012). Shared cognitive processes underlying past and future thinking: the impact of imagery and concurrent task demands on event specificity. *Journal of Experimental Psychology, 38*(2), 356-365.

Antonietti, A., & Gioletta, M. A. (1995). Individual differences in analogical problem solving. *Personality and Individual Differences, 18*(5), 611-619. https://doi.org/http://dx.doi.org/10.1016/0191-8869(94)00187-W

Australia drops in PISA rankings: Should we be worried? (2019, 07 12 2019). *Education Matters*. https://www.educationmattersmag.com.au/australia-drop-in-pisa-rankings-should-we-worried/

Australian Academy of Science. (2012). *Primary connections: Linking science with literacy*. Australian Academy of Science. Retrieved 25 November 2021 from https://primaryconnections.org.au/

Australian Broadcasting Commission. (2014). *NAPLAN results show South Australian students behind national average*. Australian Broadcasting Commission. Retrieved January 31, 2022 from https://www.abc.net.au/news/2014-08-18/naplan-results-show-sa-students-behind-national-average/5677286

(2017). *Australian Curriculum* http://www.australiancurriculum.edu.au/Curriculum/Overview

Bae, C., & Lai, M. (2020). Opportunities to participate in science learning and student engagement: A mixed methods approach to examining person and context factors. *J Educ Psychol, 112*(6), 1128-1153. https://doi.org/10.1037/edu0000410

Baker, D. L., Basaraba, D. L., Smolkowski, K., Conry, J., Hautala, J., Richardson, U., English, S., & Cole, R. (2017). Exploring the cross-linguistic transfer of reading skills in Spanish to English in the context of a computer adaptive reading intervention. *Bilingual Research Journal, 40*(2), 222-239. https://doi.org/10.1080/15235882.2017.1309719

Bardach, L., Oczlon, S., Pietschnig, J., & Luftenegger, M. (2020). Has achievement goal theory been right? A meta-analysis of the relation between goal structures and personal achievement goals. *J Educ Psychol, 112*(6), 1197-1220. https://doi.org/10.1037/edu0000419

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin, 128*(4), 612-637.

Barron, K. E., & Harackiewicz, J. M. (2001). Achievement goals and optimal motivation: Testing multiple goal models. *Journal of Personality & Social Psychology., 80*(5), 706-722.

Barron, K. E., & Harackiewicz, J. M. (2003). Revisiting the benefits of performance-approach goals in the college classroom: exploring the role of goals in advanced college courses. *International Journal of Educational Research, 39*(4–5), 357-374. https://doi.org/http://dx.doi.org/10.1016/j.ijer.2004.06.004

Barth-Cohen, L. A., & Wittmann, M. C. (2017). Aligning coordination class theory with a new context: Applying a theory of individual learning to group learning. *Science Education, 101*(2), 333-363. https://doi.org/10.1002/sce.21264

Bassok, M., & Holyoak, K. J. (1989). Interdomain transfer between isomorphic topics in algebra and physics. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 15*(1), 153-166.

Beach, K. (1999). Consequential transitions: A sociocultural expedition beyond transfer in education. In *Review of Research in Education* (Vol. 24, pp. 101-139). https://doi.org/10.3102/0091732x024001101

Beck, J. W., & Schmidt, A. M. (2013). State-level goal orientations as mediators of the relationship between time pressure and performance: A longitudinal study. *Journal of Applied Psychology, 98*(2), 354-363.

Beker, K., Kim, J., Van Boekel, M., van den Broek, P., & Kendeou, P. (2019). Refutation texts enhance spontaneous transfer of knowledge. *Contemporary Educational Psychology, 56*, 67-78. https://doi.org/https://doi.org/10.1016/j.cedpsych.2018.11.004

Belenky, D., & Nokes-Malach, T. J. (2012). Motivation and transfer: the role of mastry-approach goals in preparation for future learning. *Journal of the Learning Sciences, 21*(3), 399-432.

Bell, B. (2005). *Learning in science The Waikato research*.Oxford, United Kingdom: Routledge-Falmer Taylor Francis Group.

Belland, B. R., Kim, C., & Hannafin, M. J. (2013). A framework for designing scaffolds that improve motivation and cognition. *Educational Psychologist, 48*(4), 243-270. https://doi.org/10.1080/00461520.2013.838920

Benander, R. (2018). *A literature summary for research on transfer of learning* (Future of Education and Skills 2030: Conceptual Learning Framework, Issue. O.E.C.D.

Bereby-Meyer, Y., Moran, S., & Unger-Aviram, E. (2004). When performance goals deter performance: Transfer of skills in integrative negotiations. *Organizational Behavior and Human Decision Processes, 93*(2), 142-154. https://doi.org/http://dx.doi.org/10.1016/j.obhdp.2003.11.001

Bernacki, M., Nokes-Malach, T., Richey, J. E., & Belenky, D. M. (2016). Science diaries: a brief writing intervention to improve motivation to learn science. *Educational Psychology, 36*(1), 26-46. https://doi.org/10.1080/01443410.2014.895293

Bernard, M. E. (2001). *Program Achieve: A curriculum of lessons for teaching students how to achieve success and develop social-emotional-behavioural well-being.* (2nd ed.).Laguna Beach, California.: You Can Do It Education.

Beveridge, M., & Parkins, E. (1987). Visual representation in analogical problem solving [journal article]. *Memory & Cognition, 15*(3), 230-237. https://doi.org/10.3758/bf03197721

Biggs, J. B., & Collis, K. F. (1982). *Evaluating the quality of learning : the SOLO taxonomy (Structure of the Observed Learning Outcome)*.New York ; London: Academic Press

Bjork, E. L., Little, J. L., & Storm, B. C. (2014). Multiple-choice testing as a desirable difficulty in the classroom. *Journal of Applied Research in Memory and Cognition, 3*(3), 165-170. https://doi.org/http://dx.doi.org/10.1016/j.jarmac.2014.03.002

Blackwell, L. S., Trzesniewski, K. H., & Dweck, C. S. (2007). Implicit theories of intelligence predict achievement across an adolescent transition: A longitudinal study and an intervention. *Child Development, 78*(1), 246-263. https://doi.org/10.1111/j.1467-8624.2007.00995.x

Blume, B. D., Ford, J. K., Baldwin, T. T., & Huang, J. L. (2010). Transfer of training: A meta-analytic review. *Journal of Management, 36*(4), 1065-1105. https://doi.org/10.1177/0149206309352880

Blumenfeld, P. C., & Meece, J. L. (1988). Task factors, teacher behavior, and students' involvement and use of learning strategies in science. *The Elementary School Journal, 88*(3), 235-250. www.jstor.org/stable/1001954

Boden, K. K., Zepeda, C. D., & Nokes-Malach, T. J. (2020). Achievement goals and conceptual learning: An examination of teacher talk. *Journal of Educational Psychology, 112*(6), 1221-1242. https://doi.org/10.1037/edu0000421

Braithwaite, D. W., & Goldstone, R. L. (2015). Effects of variation and prior knowledge on abstract concept learning. *Cognition and Instruction, 33*(3), 226-256. https://doi.org/10.1080/07370008.2015.1067215

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience and school*.Washington, DC: Washington, DC: National Acad. Pr. https://doi.org/10.17226/6160

Bransford, J. D., & Schwartz, D. L. (1999). Chapter 3: Rethinking Transfer: A Simple Proposal With Multiple Implications. *Review of Research in Education, 24*(1), 61-100. https://doi.org/10.3102/0091732x024001061

Braten, I., & Olaussen, B. S. (2005). Profiling individual differences in student motivation: a longitudinal cluster-analytic study in different academic contexts. *Contemporary Educational Psychology, 30*, 359-396.

Brookes, D. T., Ross, B. H., & Mestre, J. P. (2011, 04/07/). Specificity, transfer, and the development of expertise. *Physical Review Special Topics - Physics Education Research, 7*(1), 010105. http://link.aps.org/doi/10.1103/PhysRevSTPER.7.010105

Brown, A. L., & Kane, M. J. (1988). Preschool children can learn to transfer: Learning to learn and learning from example. *Cognitive Psychology, 20*(4), 493-523. https://doi.org/http://dx.doi.org/10.1016/0010-0285(88)90014-X

Butler, A. C. (2010). Repeated testing produces superior transfer of learning relative to repeated studying. *Journal of Experimental Psychology, 36*(5), 1118-1133.

Bybee, R. W. (2015). *The BSCS 5E instructional model : Creating teachable moments* Arlington, Virginia : NSTA Press.

Cairns, D., & Areepattamannil, S. (2019). Exploring the relations of inquiry-based teaching to science achievement and dispositions in 54 countries. *Research in Science Education, 49*(1), 1-23. https://doi.org/10.1007/s11165-017-9639-x

Calais, G. G. (2006). Haskell's taxonomies of transfer of learning: implications for classroom instruction. *National Forum of Applied Educational Research Journal, 19*(3), 1-8.

Catrambone, R., Craig, D. L., & Nersessian, N. J. (2006). The role of perceptually represented structure in analogical problem solving [journal article]. *Memory & Cognition, 34*(5), 1126-1132. https://doi.org/10.3758/bf03193258

Catrambone, R., & Holyoak, K. J. (1989). Overcoming contextual limitations on problem-solving transfer. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 15*(6), 1147-1156.

CEDA. (2015). *Australia's future workforce?* CEDA. https://cedakenticomedia.blob.core.windows.net/cedamediacontainer/kentico/media/researchcataloguedocuments/research%20and%20policy/pdf/26792-futureworkforce_june2015.pdf

Chase, C. C., Malkiewich, L., & S. Kumar, A. (2019). Learning to notice science concepts in engineering activities and transfer situations. *Science Education, 103*(2), 440-471. https://doi.org/10.1002/sce.21496

Chen, C. (2010). Teaching problem solving and database skills that transfer. *Journal of Business Research, 63*(2), 175-181. https://doi.org/http://dx.doi.org/10.1016/j.jbusres.2009.03.005

Chen, J. A. (2012). Implicit theories, epistemic beliefs, and science motivation: A person-centered approach. *Learning and Individual Differences, 22*(6), 724-735, Article means, z score. https://doi.org/http://dx.doi.org/10.1016/j.lindif.2012.07.013

Chen, J. A., & Pajares, F. (2010). Implicit theories of ability of Grade 6 science students: Relation to epistemological beliefs and academic motivation and achievement in science. *Contemporary*

Educational Psychology, 35(1), 75-87, Article path analysis, ANCOVA, t-test. https://doi.org/http://dx.doi.org/10.1016/j.cedpsych.2009.10.003

Chen, Z., & Daehler, M. W. (1992). Intention and outcome: Key components of causal structure facilitating mapping in children's analogical transfer. *Journal of Experimental Child Psychology, 53*(3), 237-257. https://doi.org/http://dx.doi.org/10.1016/0022-0965(92)90038-8

Chen, Z., & Mo, L. (2004). Schema induction in problem solving: A multidimensional analysis. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 30*(3), 583-600.

Chi, M. T. H. (2009). Active-constructive-interactive: A conceptual framework for differentiating learning activities. *Topics in Cognitive Science, 1*(1), 73-105. https://doi.org/10.1111/j.1756-8765.2008.01005.x

Chi, M. T. H. (2013). Two kinds and four subtypes of misconcepived knowledge, ways to change it and the leanring outcomes. In S. Vosniadou (Ed.), *International Handbook of Research on Conceptual Change* (2nd ed. ed., pp. 49-70). London : Taylor & Francis Group.

Chi, M. T. H., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive Science, 13*(2), 145-182. https://doi.org/http://dx.doi.org/10.1016/0364-0213(89)90002-5

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5*(2), 121-152. https://doi.org/http://dx.doi.org/

Chi, M. T. H., & VanLehn, K. A. (2012). Seeing deep structure from the interactions of surface features. *Educational Psychologist, 47*(3), 177-188. https://doi.org/10.1080/00461520.2012.695709

Chin, C., & Brown, D. E. (2000). Learning in science: A comparison of deep and surface approaches. *Journal of research in science teaching, 37*(2), 109-138. https://doi.org/10.1002/(sici)1098-2736(200002)37:2<109::aid-tea3>3.0.co;2-7

Chung, G. K. w. k., Delacruz, G. C., Dionne, G. B., Baker, E. L., Lee, J. J., & Osmundson, E. (2016). *Towards individualized instruction with technology-enabled tools and methods: an exploratory study* (CRESST report, Issue.

Clark, D. B., D'Angelo, C. M., & Schleigh, S. P. (2011). Comparison of students' knowledge structure coherence and understanding of force in the Philippines, Turkey, China, Mexico, and the United States. *Journal of the Learning Sciences, 20*(2), 207-261. https://doi.org/10.1080/10508406.2010.508028

Conner, L. N. (2021). *Integrating STEM in higher education : Addressing global issues*.Milton, United Kingdom: Taylor & Francis Group.

Connolly, N. (2017). *NAP sample assessment science literacy 2015*. A. c. A. a. R. Authority. https://www.nap.edu.au/docs/default-source/default-document-library/20170309-nap_sl_final.pdf?sfvrsn=c4376d5e_2

Cooper, G., & Sweller, J. (1987). Effects of schema acquisition and rule automation on mathematical problem-solving transfer. *Journal of Educational Psychology, 79*(4), 347-362.

Council of Australian Governments Education Council. (2019). *Alice Springs (Mparntwe) education declaration*. Education Services Australia. http://www.educationcouncil.edu.au/site/DefaultSite/filesystem/documents/Reports%20and%20publications/Alice%20Springs%20(Mparntwe)%20Education%20Declaration.pdf

Crisp, V., Johnson, M., & Constantinou, F. (2018). A question of quality: Conceptualisations of quality in the context of educational test questions. *Research in Education, 105*(1), 18-41. https://doi.org/10.1177/0034523717752203

Cui, L., Rebello, N. S., & Bennett, A. G. (2006). College students' transfer from calculus to physics. *AIP Conference Proceedings, 818*(1), 37-40. https://doi.org/10.1063/1.2177017

Day, S. B., & Goldstone, R. L. (2011). Analogical transfer from a simulated physical system. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 37*(3), 551-567.

Day, S. B., & Goldstone, R. L. (2012). The Import of knowledge export: Connecting findings and theories of transfer of learning. *Educational Psychologist, 47*(3), 153-176. https://doi.org/10.1080/00461520.2012.696438

Day, S. B., Motz, B. A., & Goldstone, R. L. (2015). The cognitive costs of context: The effects of concreteness and immersiveness in instructional examples [Original Research]. *Frontiers in Psychology, 6*, 1-13. https://doi.org/10.3389/fpsyg.2015.01876

Deakin Crick, R., & Goldspink, C. (2014). Learner dispositions, self-theories and student engagement. *British Journal of Educational Studies, 62*(1), 19-35. https://doi.org/10.1080/00071005.2014.904038

Deakin Crick, R., Huang, S., Ahmed Shafi, A., & Goldspink, C. (2015). Developing resilient agency in learning: The internal structure of learning power. *British Journal of Educational Studies, 63*(2), 121-160. https://doi.org/10.1080/00071005.2015.1006574

D. f. E. a. C. Development. (2016). *STEM learning strategy for DECD preschool to year 12 2017-2020* Government of South Ausralia.

DECD. (2017a). *Learning design, assessment and moderation strategy overview* Government of South Australia. https://tfelatnps.edublogs.org/files/2018/05/handout-LDAM-strategy-overview-1a1pp8w-rywn0k.pdf

DECD. (2017b). *Reporting on Australian Curriculum in DECD schools Reception - Year 10 v1.0* Government of South Australia. https://myintranet.learnlink.sa.edu.au/library/document-library/controlled-procedures/reporting-on-australian-curriculum-in-decd-schools-reception-to-year-ten-procedure.pdf

DECD. (2016). *Reporting resource A to E guide* Government of South Australia. https://edi.sa.edu.au/library/document-library/controlled-procedures/reporting-on-australian-curriculum-in-department-for-education-schools-reception-to-year-10-procedure/reporting-resource-a-to-e-guide

DECS. (2010). *South Australian teaching for effective learning guide* Government of South Australia, . https://www.decd.sa.gov.au/sites/g/files/net691/f/tfel_framework_guide_complete.pdf

Detterman, D. K. (1993). The case for the prosecution: transfer as an epiphenomenon. In D. K. a. S. Detterman, R.J. (Ed.), *Transfer on Trial: Intelligence, Cognition and Instruction* (pp. 39-67). Ablex Publishing Corp.

Dias, N. M., & Seabra, A. G. (2017). Intervention for executive functions development in early elementary school children: effects on learning and behaviour, and follow-up maintenance. *Educational Psychology, 37*(4), 468-486. https://doi.org/10.1080/01443410.2016.1214686

Dinsmore, D. L., Baggetta, P., Doyle, S., & Loughlin, S. M. (2014). The role of initial learning, problem features, prior knowledge, and pattern recognition on transfer success. *The Journal of Experimental Education, 82*(1), 121-141. https://doi.org/10.1080/00220973.2013.835299

DiSessa, A. A. (2002). Why "conceptual ecology" is a good idea. In M. Limon & L. Mason (Eds.), *Reconsidering Conceptual Change: Issues in Theory and Practice* (pp. 29-60). Kluwer Academic Publishers.

DiSessa, A. A. (2004). Metarepresentation: Native competence and targets for instruction. *Cognition and Instruction, 22*(3), 293-331. https://doi.org/10.1207/s1532690xci2203_2

DiSessa, A. A., & Sherin, B. L. (1998). What changes in conceptual change? *International Journal of Science Education, 20*(10), 1155-1191. https://doi.org/10.1080/0950069980201002

DiSessa, A. A., & Wagner, J. F. (2005). What coordination has to say about transfer. In J. p. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. 121-154). Information Age Publishing.

Dori, Y. J., & Sasson, I. (2013). A three-attribute transfer skills framework - part I: establishing the model and its relation to chemical education [10.1039/C3RP20093K]. *Chemistry Education Research and Practice, 14*(4), 363-375. https://doi.org/10.1039/C3RP20093K

Du, X., & Zhang, Q. (2019). Tracing worked examples: effects on learning in geometry. *Educational Psychology, 39*(2), 169-187. https://doi.org/10.1080/01443410.2018.1536256

Duff, A., & McKinstry, S. (2007). Students' approaches to learning. *Issues in accounting education, 22*(2), 183-214. https://doi.org/10.2308/iace.2007.22.2.183

Dufresne, R., Mestre, J., Thaden-Koch, T. C., Gerace, W. J., & Leonard, W. J. (2005). Knowledge representation and coordination. *AIP Conference Proceedings, 790*(1), 155-215. https://doi.org/doi:http://dx.doi.org/10.1063/1.2084687

Duncker, K. (1945). On problem-solving. *Psychological Monographs: General and Applied, 58*(5), i-113.

Dupeyrat, C., & Mariné, C. (2005). Implicit theories of intelligence, goal orientation, cognitive engagement, and achievement: A test of Dweck's model with returning to school adults. *Contemporary Educational Psychology, 30*(1), 43-59. https://doi.org/http://dx.doi.org/10.1016/j.cedpsych.2004.01.007

Dweck, C. S., & Yeager, D. S. (2019). Mindsets: A view from two eras. *Perspectives on Psychological Science, 14*(3), 481-496. https://doi.org/10.1177/1745691618804166

Edmondson, K. M., & Novak, J. D. (1993). The interplay of scientific epistemological views, learning strategies, and attitudes of college students. *Journal of research in science teaching, 30*(6), 547-559. https://doi.org/10.1002/tea.3660300604

Ellis, A. B. (2007). A taxonomy for categorizing generalizations: Generalizing actions and reflection generalizations. *Journal of the Learning Sciences, 16*(2), 221-262. https://doi.org/10.1080/10508400701193705

Ellis, H. C. (1965). *The transfer of learning*.New York, USA: The MacMillan Company.

Engle, R. A. (2006). Framing interactions to foster generative learning: A situative explanation of transfer in a community of learners classroom. *Journal of the Learning Sciences, 15*(4), 451-498. https://doi.org/10.1207/s15327809jls1504_2

Engle, R. A. (2012). The resurgence of research Into transfer: An introduction to the final articles of the transfer strand. *Journal of the Learning Sciences, 21*(3), 347-352. https://doi.org/10.1080/10508406.2012.707994

Engle, R. A., Lam, D. P., Meyer, X. S., & Nix, S. E. (2012). How does expansive framing promote transfer? Several proposed explanations and a research agenda for investigating them. *Educational Psychologist, 47*(3), 215-231. https://doi.org/10.1080/00461520.2012.695678

Engle, R. A., Nguyen, P. D., & Mendelson, A. (2011). The influence of framing on transfer: initial evidence from a tutoring experiment [journal article]. *Instructional Science, 39*(5), 603-628. https://doi.org/10.1007/s11251-010-9145-2

Farmer, T. W. (2020). Reforming research to support culturally and ecologically responsive and developmentally meaningful practice in schools. *Educational Psychologist, 55*(1), 32-39. https://doi.org/10.1080/00461520.2019.1698298

Fauth, B., Wagner, W., Bertram, C., Gollner, R., Roloff, J., Ludtke, O., Polikoff, M., Klusmann, U., & Trautwein, U. (2020). Don't blame the teacher? The need to account for classroom characteristics in evaluations of teaching quality. *J Educ Psychol, 112*(6), 1284-1302. https://doi.org/10.1037/edu0000416

Fong, G. T., Krantz, D. H., & Nisbett, R. E. (1986, 7//). The effects of statistical training on thinking about everyday problems. *Cognitive Psychology, 18*(3), 253-292. https://doi.org/http://dx.doi.org/10.1016/0010-0285(86)90001-0

Forbus, K. D., Gentner, D., & Law, K. (1995). MAC/FAC: A model of similarity-based retrieval. *Cognitive Science, 19*(2), 141-205. https://doi.org/10.1207/s15516709cog1902_1

Fort, D. G., Herr, T. M., Shaw, P. L., Gutzman, K. E., & Starren, J. B. (2017). Mapping the evolving definitions of translational research. *Journal of clinical and translational science, 1*(1), 60-66. https://doi.org/10.1017/cts.2016.10

Foster, M. (2020). *Developing student agency In South Australia seeing our learners anew - "Don't waste a crisis"*. Qatar foundation. Retrieved 26/10/2021 from https://www.wise-qatar.org/developing-student-agency-in-south-australia-seeing-our-learners-anew-dont-waste-a-crisis/

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: potential of the concept, state of the evidence. *Review of Educational Research, 74*(1), 59-109. https://doi.org/10.3102/00346543074001059

Gabriel, F., Signolet, J., & Westwell, M. (2018). A machine learning approach to investigating the effects of mathematics dispositions on mathematical literacy. *International Journal of*

Research & Method in Education, 41(3), 306-327. https://doi.org/10.1080/1743727X.2017.1301916

Gagne, R. M. (1965). *The conditions of learning and theory of instruction* (1st ed.).New York, NY: Holt, Rhinehart and Winston.

Geake, J. G. (2009). *The brain at school*.Maidenhead, Berkshire, England: McGraw- Hill Education, Open University Press.

Gee, K. A., & Wong, K. K. (2012). A cross national examination of inquiry and its relationship to student performance in science: Evidence from the Program for International Student Assessment (PISA) 2006. *International Journal of Educational Research, 53*(0), 303-318. https://doi.org/http://dx.doi.org/10.1016/j.ijer.2012.04.004

Gentner, D., & Holyoak, K. J. (1997). Reasoning and learning by analogy. *American Psychologist, 52*(1), 32-34.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology, 12*(3), 306-355. https://doi.org/http://dx.doi.org/10.1016/0010-0285(80)90013-4

Gick, M. L., & Holyoak, K. J. (1983). Schema induction and analogical transfer. *Cognitive Psychology, 15*(1), 1-38. https://doi.org/http://dx.doi.org/10.1016/0010-0285(83)90002-6

Gick, M. L., & McGarry, S. J. (1992). Learning from mistakes: Inducing analogous solution failures to a source problem produces later successes in analogical transfer. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 18*(3), 623-639.

Gick, M. L., & Paterson, K. (1992). DO contrasting examples facilitate schema acquisition and analogical transfer? *Canadian Journal of Psychology, 46*(4), 539-550.

Göçmençelebi, Ş. İ., Özkan, M., & Bayram, N. (2012). Evaluating primary school students' deep learning approach to science lessons. *International Online Journal of Educational Sciences, 4* (3), 554-562.

Goetz, E. T., & Sadoski, M. (1995). The perils of seduction - distracting details of incomprehensible abstractions. *Reading Research Quarterly, 30*(3), 500-511. https://doi.org/10.2307/747628

Goldstone, R. L., & Day, S. B. (2012). Introduction to "New Conceptualizations of Transfer of Learning". *Educational Psychologist, 47*(3), 149-152. https://doi.org/10.1080/00461520.2012.695710

Goldstone, R. L., & Sakamoto, Y. (2003). The transfer of abstract principles governing complex adaptive systems. *Cognitive Psychology, 46*(4), 414-466. https://doi.org/http://dx.doi.org/10.1016/S0010-0285(02)00519-4

Goldstone, R. L., & Son, J. Y. (2005). The transfer of scientific principles using concrete and idealized simulations. *Journal of the Learning Sciences, 14*(1), 69-110. https://doi.org/10.1207/s15327809jls1401_4

Goldwater, M. B., & Gentner, D. (2015). On the acquisition of abstract knowledge: Structural alignment and explication in learning causal system categories. *Cognition, 137*, 137-153. https://doi.org/http://dx.doi.org/10.1016/j.cognition.2014.12.001

Gooding, J., & Metz, B. (2011). From misconceptions to conceptual change. *The Science Teacher, 78*(4), 34-37.

Gott, S. P., Parker Hall, E., Pokorny, R. A., Dibble, E., & Glaser, R. (1993). A naturalistic study of transfer: Adaptive expertise in technical domains. In D. K. a. S. Detterman, R.J. (Ed.), *Transfer on Trial: Intelligence, Cognition and Instruction* (pp. 258-288). Ablex Publishing Corp.

Government of South Australia, D. f. E. (2014). *Australian curriculum SA teachers and leaders resource*. Government of South Australia. Retrieved 29 November, 2021 from https://acleadersresource.sa.edu.au/resources/sa-learning-design/

Grant, E. R., & Spivey, M. J. (2003). Eye movements and problem solving: Guiding attention guides thought. *Psychological Science, 14*(5), 462-466. https://doi.org/10.1111/1467-9280.02454

Grant, H., & Dweck, C. S. (2003). Clarifying achievement goals and their impact. *Journal of Personality & Social Psychology, 85*(3), 541-553.

Gray, K. E., & Rebello, N. S. (2005). Transfer between paired problems in an interview. *AIP Conference Proceedings, 790*(1), 157-160. https://doi.org/10.1063/1.2084725

Greene, J. A., Chinn, C. A., & Deekens, V. M. (2021). Experts' reasoning about the replication crisis: Apt epistemic performance and actor-oriented transfer. *Journal of the Learning Sciences*, 1-50. https://doi.org/10.1080/10508406.2020.1860992

Greeno, J. G. (2006). Authoritative, accountable positioning and connected, general knowing: progressive themes in understanding transfer. *Journal of the Learning Sciences, 15*(4), 537-547. https://doi.org/10.1207/s15327809jls1504_4

Greeno, J. G., Smith, D. R., & Moore, J. M. (1993). Transfer of situated learning. In D. K. a. S. Detterman, R.J. (Ed.), *Transfer on Trial: Intelligence, Cognition and Instruction* (pp. 99-167). Ablex Publishing Corp.

Grose, R. F., & Birney, R., C. (1963). *Transfer of learning* Princeton, New Jersey, USA: D. Van Nostrand Company Inc.

Hackling, M. W. (2008). *An overview of Primary Connections. Stage 3 research outcomes 2006-2008*. Australian Academy of Science. file:///C:/Users/Anne/Downloads/An%20overview%20of%20PrimaryConnections%20Stage%203%20(1).pdf

Hager, P., & Hodkinson, P. (2009). Moving beyond the metaphor of transfer of learning. *British Educational Research Journal, 35*(4), 619-638. https://doi.org/10.1080/01411920802642371

Hajian, S. (2019). Transfer of learning and teaching: A review of transfer theories and effective instructional practices. *IAFOR journal of education, 7*(1), 93-111. https://doi.org/10.22492/ije.7.1.06

Halpern, D. F. (1998). Teaching critical thinking for transfer across domains: Dispositions, skills, structure training, and metacognitive monitoring. *The American psychologist, 53*(4), 449-455. https://doi.org/10.1037/0003-066X.53.4.449

Halpern, D. F., & Hakel, M. D. (2003). Applying the science of learning to the university and beyond. *Change*, *35*(4), 36-41.

Hammer, D., Elby, A., Scherr, R., & Redish, E. F. (2005). Resources, framing and transfer. In J. P. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. 89-119). Information Age Publishing.

Harp, S. F., & Mayer, R. E. (1998). How seductive details do their damage: A theory of cognitive interest in science learning. *Journal of Educational Psychology, 90*(3), 414-434.

Hart, W., & Albarracín, D. (2009). What I was doing versus what I did: Verb aspect influences memory and future actions. *Psychological Science, 20*(2), 238-244. https://doi.org/10.1111/j.1467-9280.2009.02277.x

Hartmann, C., van Gog, T., Rummel, N., Leerstoel van, G., Education, & Learning: Development in, I. (2021). Preparatory effects of problem solving versus studying examples prior to instruction. *Instructional Science, 49*(1), 1-21. https://doi.org/10.1007/s11251-020-09528-z

Haskell, R. E. (2004). Transfer of learning. In C. D. Spielberger (Ed.), *Encyclopedia of Applied Psychology* (pp. 575-586). Elsevier. https://doi.org/https://doi.org/10.1016/B0-12-657410-3/00834-5

Haslerud, G. M., & Meyers, S. (1958). The transfer value of given and individually derived principles. *Journal of Educational Psychology, 49*(6), 293-298.

Hatano, G., & Greeno, J. G. (1999). Commentary: alternative perspectives on transfer and transfer studies. *International Journal of Educational Research, 31*(7), 645-654. https://doi.org/http://dx.doi.org/10.1016/S0883-0355(99)00029-4

Hattie, J. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement*.London: London: Routledge. https://doi.org/10.4324/9780203887332

Hattie, J., & Yates, G. C. R. (2014). *Visible learning and the science of how we learn*.London: London: Routledge. https://doi.org/10.4324/9781315885025

Hautala, J., Baker, D. L., Keurulainen, A., Ronimus, M., Richardson, U., & Cole, R. (2018). Early science learning with a virtual tutor through multimedia explanations and feedback on spoken questions. *Educational Technology Research and Development, 66*(2), 403-428. https://doi.org/10.1007/s11423-017-9558-6

Heddy, B. C., Sinatra, G. M., Seli, H., Taasoobshirazi, G., & Mukhopadhyay, A. (2016). Making learning meaningful: facilitating interest development and transfer in at-risk college students. *Educational Psychology*, 1-17. https://doi.org/10.1080/01443410.2016.1150420

Heijne-Penninga, M., Kuks, J. B. M., Hofman, W. H. A., & Cohen-Schotanus, J. (2010). assessment: Influences of deep learning, need for cognition and preparation time on open- and closed-book test performance. *Medical Education, 44*(9), 884-891. https://doi.org/10.1111/j.1365-2923.2010.03732.x

Helfenstein, S. (2006). *Transfer: review, reconstruction, resolution.* University of Jyvaskyla]. Jyvaskyla.

Helfenstein, S., & Saariluoma, P. (2005). Mental contents in transfer [journal article]. *Psychological Research, 70*(4), 293-303. https://doi.org/10.1007/s00426-005-0214-0

Helfenstein, S., & Saariluoma, P. (2007). Apperception in primed problem solving. *Cognitive Processing, 8*(4), 211-232. https://doi.org/10.1007/s10339-007-0189-4

Hendrickson, G., & Schroeder, W. H. (1941). Transfer of training in learning to hit a submerged target. [Article]. *Journal of Educational Psychology 32*(3), 205-213.

Hickey, D. T., Taasoobshirazi, G., & Cross, D. (2012). Assessment as learning: Enhancing discourse, understanding, and achievement in innovative science curricula. *Journal of research in science teaching, 49*(10), 1240-1270. https://doi.org/10.1002/tea.21056

Holyoak, K. J., & Koh, K. (1987). Surface and structural similarity in analogical transfer [journal article]. *Memory & Cognition, 15*(4), 332-340. https://doi.org/10.3758/bf03197035

Holyoak, K. J., & Thagard, P. (1997). The analogical mind. *American Psychologist, 52*(1), 35-44.

Hsu, C.-Y., Kalyuga, S., & Sweller, J. (2015). When should guidance be presented in physics instruction? *Archives of Scientific Psychology, 3*(1), 37-53. https://doi.org/10.1037/arc0000012

Hu, W., Jia, X., Plucker, J. A., & Shan, X. (2016). Effects of a critical thinking skills program on the learning motivation of primary school students. *Roeper Review, 38*(2), 70-83. https://doi.org/10.1080/02783193.2016.1150374

International Association for the Evaluation of Educational Achievement (IAC). (2013). *TIMSS 2011 assessment released science items Grade 4*. https://nces.ed.gov/timss/pdf/TIMSS2011_G4_Science.pdf

Irvine, J. (2017). A comparison of revised bloom and marzano's new taxonomy of learning. *Research in Higher Education Journal, 33*, 1-16.

Jaakkola, T., & Veermans, K. (2018). Exploring the effects of concreteness fading across grades in elementary school science education. *Instructional Science, 46*(2), 185-207. https://doi.org/10.1007/s11251-017-9428-y

Jacot, A., Raemdonck, I., & Frenay, M. (2015). A review of motivational constructs in learning and training transfer [journal article]. *Zeitschrift für Erziehungswissenschaft, 18*(1), 201-219. https://doi.org/10.1007/s11618-014-0599-x

Jensen, J. L., McDaniel, M. A., Woodard, S. M., & Kummer, T. A. (2014). Teaching to the test…or testing to teach: Exams requiring higher order thinking skills encourage greater conceptual understanding [journal article]. *Educational Psychology Review, 26*(2), 307-329. https://doi.org/10.1007/s10648-013-9248-9

Judd, C. H. (1908). The relationship of special training to general intelligence. *Educational Review, 36*, 28-42.

Kachergis, G., Rhodes, M., & Gureckis, T. (2017). Desirable difficulties during the development of active inquiry skills. *Cognition, 166*, 407-417. https://doi.org/https://doi.org/10.1016/j.cognition.2017.05.021

Kaminski, J. A., Sloutsky, V. M., & Heckler, A. F. (2013). The cost of concreteness: The effect of nonessential information on analogical transfer. *Journal of Experimental Psychology: Applied, 19*(1), 14-29.

Kaplan, A., Gheen, M., & Midgley, C. (2002, Jun). Classroom goal structure and student disruptive behaviour. *Br J Educ Psychol, 72*(Pt 2), 191-211.

Kappes, H. B., Stephens, E. J., & Oettingen, G. (2011). Implicit theories moderate the relation of positive future fantasies to academic outcomes. *Journal of Research in Personality, 45*(3), 269-278. https://doi.org/http://dx.doi.org/10.1016/j.jrp.2011.02.006

Kapur, M. (2015). Learning from productive failure. *Learning: Research and Practice, 1*(1), 51-65. https://doi.org/10.1080/23735082.2015.1002195

Kapur, M., & Bielaczyc, K. (2011). Designing for productive failure. *Journal of the Learning Sciences, 21*(1), 45-83. https://doi.org/10.1080/10508406.2011.591717

Katona, G. (1942). On different forms of learning by reading. *Journal of Educational Psychology, 33*(5), 335-355.

Keane, M. (1987). On retrieving analogues when solving problems. *The Quarterly Journal of Experimental Psychology Section A, 39*(1), 29-41. https://doi.org/10.1080/02724988743000015

Kelley, T. R., Capobianco, B. M., & Kaluf, K. J. (2015). Concurrent think-aloud protocols to assess elementary design students [journal article]. *International Journal of Technology and Design Education, 25*(4), 521-540. https://doi.org/10.1007/s10798-014-9291-y

Kember, D., Biggs, J., & Leung, D. Y. P. (2004). Examining the multidimensionality of approaches to learning through the development of a revised version of the Learning Process Questionnaire. *British Journal of Educational Psychology, 74*, 261-279. http://search.proquest.com/docview/216965917?accountid=10910

Kesidou, S., Sadeghi, R., & Marosszeky, N. (2013). *National Assessment Program - science literacy school release materials*. A. a. R. A. Australian Curriculum. http://www.nap.edu.au/_resources/NAP-SL_2012_School_Release_Materials.pdf

Kesidou, S., Sadeght, R and Marosszeky, N. (2012). *National Assessment Program - science literacy year 6 report*. ACARA. http://www.nap.edu.au/verve/_resources/NAP-SL_2012_Public_Report.pdf

Kim, Y. R. (2013). *Effects of worked examples on far transfer* (Publication Number 1545092) [M.A., The University of North Carolina at Chapel Hill]. ProQuest Dissertations & Theses Global. Ann Arbor.

King, R. B. (2012). How you think about your intelligence influences how adjusted you are: Implicit theories and adjustment outcomes. *Personality and Individual Differences, 53*(5), 705-709. https://doi.org/http://dx.doi.org/10.1016/j.paid.2012.05.031

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006, 2006/06/01). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75-86. https://doi.org/10.1207/s15326985ep4102_1

Kohn, M. S. (2016). *Factors that inhibit or facilitate transfer of learning: A replication study* [Ph.D., Capella University]. ProQuest Dissertations & Theses Global. Ann Arbor.

Kornilova, T. V., Kornilov, S. A., & Chumakova, M. A. (2009). Subjective evaluations of intelligence and academic self-concept predict academic achievement: Evidence from a selective student population. *Learning and Individual Differences, 19*(4), 596-608. https://doi.org/http://dx.doi.org/10.1016/j.lindif.2009.08.001

Kruit, P. M., Oostdam, R. J., van den Berg, E., & Schuitema, J. A. (2018). Effects of explicit instruction on the acquisition of students' science inquiry skills in grades 5 and 6 of primary education. *International Journal of Science Education, 40*(4), 421-441. https://doi.org/10.1080/09500693.2018.1428777

Kurtz, K. J., & Loewenstein, J. (2007). Converging on a new role for analogy in problem solving and retrieval: when two problems are better than one [journal article]. *Memory & Cognition, 35*(2), 334-341. https://doi.org/10.3758/bf03193454

Larsen-Freeman, D. (2013). Transfer of learning transformed. *Language Learning, 63*, 107-129. https://doi.org/10.1111/j.1467-9922.2012.00740.x

Lave, J. (1988). *Cognition in practice: mind, mathematics and culture in everyday life*.Cambridge, New York: Cambridge University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*.Cambridge, England: Cambridge University Press.

Law, Y. K., Chan, C. K., & Sachs, J. (2008, Mar). Beliefs about learning, self-regulated strategies and text comprehension among Chinese children. *Br J Educ Psychol, 78*(Pt 1), 51-73. https://doi.org/10.1348/000709907x179812

Leberman, S., McDonald, L., & Doyle, S. (2016). *The transfer of learning. Participant's Perspectives of adult education and training*.Alserchot, Hampshire, England: Gower Publishing Company.

Leimbach, M. (2010). Learning transfer model: a research-driven approach to enhancing learning effectiveness. *Industrial and Commercial Training, 42*(2), 81-86. https://doi.org/http://dx.doi.org/10.1108/00197851011026063

Levrini, O., & diSessa, A. A. (2008). How students learn from multiple contexts and definitions: Proper time as a coordination class. *Physical Review Special Topics - Physics Education Research, 4*(1), 010107. http://link.aps.org/doi/10.1103/PhysRevSTPER.4.010107

Levrini, O., Fantini, P., Tasquier, G., Pecori, B., & Levin, M. (2015). Defining and operationalizing appropriation for science learning. *Journal of the Learning Sciences, 24*(1), 93-136. https://doi.org/10.1080/10508406.2014.928215

Lim, J., Reiser, R. A., & Olina, Z. (2009). The effects of part-task and whole-task instructional approaches on acquisition and transfer of a complex cognitive skill. *Educational Technology, Research and Development, 57*(1), 61-77.

Lipko-Speed, A., Dunlosky, J., & Rawson, K. A. (2014). Does testing with feedback help grade-school children learn key concepts in science? *Journal of Applied Research in Memory and Cognition, 3*(3), 171-176. https://doi.org/http://dx.doi.org/10.1016/j.jarmac.2014.04.002

Litchfield, D., & Ball, L. J. (2011). Using another's gaze as an explicit aid to insight problem solving. *The Quarterly Journal of Experimental Psychology, 64*(4), 649-656. https://doi.org/10.1080/17470218.2011.558628

Lleixà, T., González-Arévalo, C., & Braz-Vieira, M. (2016). Integrating key competences in school physical education programmes. *European Physical Education Review, 22*(4), 506-525. https://doi.org/10.1177/1356336x15621497

Lobato, J. (2006). Alternative perspectives on the transfer of learning: History, issues, and challenges for future research. *Journal of the Learning Sciences, 15*(4), 431-449. https://doi.org/10.1207/s15327809jls1504_1

Lobato, J. (2012). The actor-oriented transfer perspective and its contributions to educational research and practice. *Educational Psychologist, 47*(3), 232-247. https://doi.org/10.1080/00461520.2012.693353

Lobato, J., Rhodehamel, B., & Hohensee, C. (2012). “Noticing” as an alternative transfer of learning process. *Journal of the Learning Sciences, 21*(3), 433-482. https://doi.org/10.1080/10508406.2012.682189

Maciejewski, W., & Merchant, S. (2016). Mathematical tasks, study approaches, and course grades in undergraduate mathematics: a year-by-year analysis. *International Journal of Mathematical Education in Science and Technology, 47*(3), 373-387. https://doi.org/10.1080/0020739X.2015.1072881

Mandler, J. M., & Orlich, F. (2013). Analogical transfer: The roles of schema abstraction and awareness [journal article]. *Bulletin of the Psychonomic Society, 31*(5), 485-487. https://doi.org/10.3758/bf03334970

Marsh, C. (2007). Strategic knowledge of computer applicaitons: the key to efficient computer use. (Technical report). *Issues in Informing Science and Information Technology, 2007*(4), 269-277.

Martin, A. J., Mansour, M., & Malmberg, L.-E. (2020). What factors influence students' real-time motivation and engagement? An experience sampling study of high school students using mobile technology. *Educational Psychology, 40*(9), 1113-1135. https://doi.org/10.1080/01443410.2018.1545997

Marton, F. (2006). Sameness and difference in transfer. *Journal of the Learning Sciences, 15*(4), 499-535. https://doi.org/10.1207/s15327809jls1504_3

Marzano, R. J., & Kendall, J. S. (2007). *The new taxonomy of educational objectives*.Thousand Oaks, CA, U.S.A.: Corwin press.

May, W., Chung, E.-K., Elliott, D., & Fisher, D. (2012). The relationship between medical students' learning approaches and performance on a summative high-stakes clinical performance examination. *Medical Teacher, 34*(4), e236-e241. https://doi.org/doi:10.3109/0142159X.2012.652995

Mayer, R. E. (1975). Information processing variables in learning to solve problems. *Review of Educational Research, 45*(4), 525-541. https://doi.org/10.3102/00346543045004525

McCullum, C. C. (2017). *An examination of the factors that influence the transfer of learning among k-12 educators participating in professional learning communities (Doctoral dissertation)* (Publication Number 10620576) [Ed.D., The University of Southern Mississippi]. ProQuest Central; ProQuest Dissertations & Theses Global; Social Science Premium Collection. Ann Arbor.

McDaniel, M. A., Thomas, R. C., Agarwal, P. K., McDermott, K. B., & Roediger, H. L. (2013). Quizzing in middle-school science: Successful Transfer performance on classroom exams. *Applied Cognitive Psychology, 27*(3), 360-372. https://doi.org/10.1002/acp.2914

McKeachie, W. J. (1987). Cognitive skills and their transfer: Discussion. *International Journal of Educational Research, 11*(6), 707-712. https://doi.org/10.1016/0883-0355(87)90010-3

McNeil, N. M., & Fyfe, E. R. (2012). "Concreteness fading" promotes transfer of mathematical knowledge. *Learning and Instruction, 22*(6), 440-448. https://doi.org/http://dx.doi.org/10.1016/j.learninstruc.2012.05.001

Melby-Lervag, M., & Hulme, C. (2013). Is working memory training effective? A Meta-analytic review. *Developmental Psychology, 49*(2), 270-291.

Melo, M., & Miranda, G. l. (2015). Learning electrical circuits: The effects of 4c-id instructional approach in the acquision and transfer of knowledge. *Journal of Information Technology Education: Research 14*, 313-337.

Mestre, J. (2005). Is Transfer ubiquitous or rare? New paradigms for studying transfer. *AIP Conference Proceedings, 790*(1), 3-6. https://doi.org/doi:http://dx.doi.org/10.1063/1.2084687

Mestre, J. P. (2002). Probing adults' conceptual understanding and transfer of learning via problem posing. *Journal of Applied Developmental Psychology, 23*(1), 9-50. https://doi.org/http://dx.doi.org/10.1016/S0193-3973(01)00101-0

Mestre, J. P., Dufresne, R. J., Gerace, W. J., Hardiman, P. T., & Touger, J. S. (1993). Promoting skilled problem-solving behavior among beginning physics students. *Journal of research in science teaching, 30*(3), 303-317. https://doi.org/10.1002/tea.3660300306

Middleton, M., & Midgley, C. (1997). Avoiding the demonstration of lack of ability: An underexplored aspect of goal theory. *Journal of Educational Psychology 89*(4), 710-718.

Miki, K., & Yamauchi, H. (2005). Perceptions of classroom goal structures, personal achievement goal orientations, and learning strategies. *The Japanese Journal of Psychology, 76*(3), 260-268.

Mitchell, P. (2016). *From concept to classroom: What is translational research*. Australian Council for Educational Research. https://research.acer.edu.au/professional_dev/9

Montpetit-Tourangeau, K., Dyer, J. O., Hudon, A., Windsor, M., Charlin, B., Mamede, S., & van Gog, T. (2017, Dec 1). Fostering clinical reasoning in physiotherapy: comparing the effects of concept map study and concept map completion after example study in novice and advanced learners. *BMC Med Educ, 17*(1), 238. https://doi.org/10.1186/s12909-017-1076-z

Moser, A., Zimmermann, L., Dickerson, K., Grenell, A., Barr, R., & Gerhardstein, P. (2015). They can interact, but can they learn? Toddlers' transfer learning from touchscreens and television. *Journal of Experimental Child Psychology, 137*, 137-155. https://doi.org/http://dx.doi.org/10.1016/j.jecp.2015.04.002

Nikata, K., & Shimada, H. (2005). Facilitation of analogical transfer by posing an analogous problem for oneself. *The Japanese Journal of Educational Psychology, 53*(3), 381-392. https://doi.org/10.5926/jjep1953.53.3_381

Nokes-Malach, T. J., Meade, M. L., & Morrow, D. G. (2012). The effect of expertise on collaborative problem solving. *Thinking & Reasoning, 18*(1), 32-58. https://doi.org/10.1080/13546783.2011.642206

Nokes-Malach, T. J., & Mestre, J. P. (2013). Toward a model of transfer as sense-making. *Educational Psychologist, 48*(3), 184-207. https://doi.org/10.1080/00461520.2013.807556

Nokes-Malach, T. J., VanLehn, K., Belenky, D. M., Lichtenstein, M., & Cox, G. (2012). Coordinating principles and examples through analogy and self-explanation [journal article]. *European Journal of Psychology of Education, 28*(4), 1237-1263. https://doi.org/10.1007/s10212-012-0164-z

Nokes, T. J. (2009). Mechanisms of knowledge transfer. *Thinking & Reasoning, 15*(1), 1-36. https://doi.org/10.1080/13546780802490186

Nokes, T. J., & Ohlsson, S. (2005, Sep 10). Comparing multiple paths to mastery: What is learned? *Cogn Sci, 29*(5), 769-796. https://doi.org/10.1207/s15516709cog0000_32

Novick, L. R. (1988). Analogical Transfer, problem similarity, and expertise. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 14*(3), 510-520.

Ohlsson, S. (2009). Resubsumption: A possible mechanism for conceptual change and belief revision. *Educational Psychologist, 44*(1), 20-40. https://doi.org/10.1080/00461520802616267

Ohlsson, S. (2011). *Deep learning : How the mind overrides experience*.New York: Cambridge University Press.

Ozdemir, O. F. (2013). Transfer and conceptual change: the change process from the theoretical perspectives of coordination classes and phenomenological primitives. *Instructional Science, 41*(1), 81-103. https://doi.org/10.1007/s11251-012-9219-4

Pai, H.-h., Sears, D. A., & Maeda, Y. (2015). Effects of small-group learning on transfer: A meta-analysis. *Educational Psychology Review, 27*(1), 79-102. https://doi.org/http://dx.doi.org/10.1007/s10648-014-9260-8

Panizzon, D., Arthur, D., & Pegg, J. (2006). ESSA: Developing and scoping a test to explore scientific literacy and achievement in NSW. *Teaching Science, 52*(4), 22-27.

Paulick, I., Retelsdorf, J., & Möller, J. (2013). Motivation for choosing teacher education: Associations with teachers' achievement goals and instructional practices. *International Journal of Educational Research, 61*, 60-70. https://doi.org/http://dx.doi.org/10.1016/j.ijer.2013.04.001

Pedone, R., Hummel, J., & Holyoak, K. (2001). The use of diagrams in analogical problem solving. *Memory & Cognition, 29*(2), 214-221. https://doi.org/10.3758/bf03194915

Pegg, J., & Tall, D. (2005). The fundamental cycle of concept construction underlying various theoretical frameworks. *ZDM, 37*(6), 468-475. https://doi.org/10.1007/BF02655855

Perkins, D. (2009). *Making learning whole : how seven principles of teaching can transform education* (1 ed.). Wiley. http://flinders.eblib.com/patron/FullRecord.aspx?p=487701

Perkins, D. N., & Salomon, G. (1992). Transfer of learning. In *International Encyclopaedia of Education*. Pergammon Press. https://learnweb.harvard.edu/alps/thinking/docs/traencyn.htm

Perkins, D. N., & Salomon, G. (2012). Knowledge to go: A motivational and dispositional view of transfer. *Educational Psychologist, 47*(3), 248-258. https://doi.org/10.1080/00461520.2012.693354

Peters, L. W. H., ten Dam, G. T. M., Kocken, P. L., Buijs, G. J., Dusseldorp, E., & Paulussen, T. G. W. M. (2015). Effects of transfer-oriented curriculum on multiple behaviors in the Netherlands. *Health Promotion International, 30*(2), 291-309. https://doi.org/10.1093/heapro/dat039

Philippakos, Z. A., & MacArthur, C. A. (2016). The effects of giving feedback on the persuasive writing of fourth- and fifth-grade students. *Reading Research Quarterly, 51*(4), 419-433. https://doi.org/10.1002/rrq.149

Phye, G. D. (2001). Problem-solving instruction and problem-solving transfer: The correspondence issue. *Journal of Educational Psychology, 93*(3), 571-578.

Pugh, K. J., Linnenbrink-Garcia, L., Koskey, K. L. K., Stewart, V. C., & Manzey, C. (2010). Motivation, learning, and transformative experience: A study of deep engagement in science. *Science Education, 94*(1), 1-28. https://doi.org/10.1002/sce.20344

Purpura, D. J., Baroody, A. J., Eiland, M. D., & Reid, E. E. (2016). Fostering first graders' reasoning strategies with basic sums: The value of guided instruction. *The Elementary School Journal, 117*(1), 72-100. https://doi.org/10.1086/687809

Raaijmakers, S. F., Baars, M., Paas, F., van Merriënboer, J. J. G., & van Gog, T. (2018). Training self-assessment and task-selection skills to foster self-regulated learning: Do trained skills transfer across domains? *Applied Cognitive Psychology, 32*(2), 270-277. https://doi.org/https://doi.org/10.1002/acp.3392

Ramburuth, P., & Mladenovic, R. (2004). Exploring the relationship between students' orientations to learning, the structure of students' learning outcomes and subsequent academic performance. *Accounting Education, 13*(4), 507-527. https://doi.org/10.1080/0963928042000306774

Ramos, A., De Fraine, B., & Verschueren, K. (2021). Learning goal orientation in high-ability and average-ability students: Developmental trajectories, contextual predictors, and long-term educational outcomes. *Journal of Educational Psychology, 113*(2), 370-389. https://doi.org/10.1037/edu0000476

Rappolt-Schlichtmann, G., Daley, S. G., Lim, S., Lapinski, S., Robinson, K. H., & Johnson, M. (2013). Universal design for learning and elementary school science: Exploring the efficacy, use, and perceptions of a web-based science notebook. *Journal of Educational Psychology, 105*(4), 1210-1225.

Rebello, N. S., Zollman, D. A., Allbaugh, A. R., Engelhardt, P. V., Gray, K. E., Hrepic, Z., & Itza-Ortiz, S. F. (2005). Dynamic transfer. In J. P. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. 217-250). Information Age Publishing.

Reed, S. K. (2015). The structure of ill-structured (and well-structured) problems revisited [journal article]. *Educational Psychology Review*, 1-26. https://doi.org/10.1007/s10648-015-9343-1

Reed, S. K., Dempster, A., & Ettinger, M. (1985). Usefulness of analogous solutions for solving algebra word problems. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 11*(1), 106-125.

Resing, W. C. M., Bakker, M., Pronk, C. M. E., & Elliott, J. G. (2016). Dynamic testing and transfer: An examination of children's problem-solving strategies. *Learning and Individual Differences, 49*, 110-119. https://doi.org/https://doi.org/10.1016/j.lindif.2016.05.011

Resnick, L. B. (1989). Introduction. In L. B. Resnick (Ed.), *Knowing, learning and instruction. Essays in honor of Robert Glaser* (pp. 1-24). Luwrence Erlbaum and Associates.

Richey, J. E., & Nokes-Malach, T. J. (2013). How much is too much? Learning and motivation effects of adding instructional explanations to worked examples. *Learning and Instruction, 25*, 104-124. https://doi.org/http://dx.doi.org/10.1016/j.learninstruc.2012.11.006

Richland, L. E., Stigler, J. W., & Holyoak, K. J. (2012). Teaching the conceptual structure of mathematics. *Educational Psychologist, 47*(3), 189-203. https://doi.org/10.1080/00461520.2012.667065

Roid, G. (2003). *Stanford-Binet intelligence scales - SB5*.Austin, Texas, USA: Pro Ed.

Roll, I., Holmes, N. G., Day, J., & Bonn, D. (2012). Evaluating metacognitive scaffolding in guided invention activities [journal article]. *Instructional Science, 40*(4), 691-710. https://doi.org/10.1007/s11251-012-9208-7

Roorda, G., Vos, P., & Goedhart, M. J. (2015). An actor-oriented transfer perspective on high school students' development of the use of procedures to solve problems on rate of change. [journal article]. *International Journal of Science and Mathematics Education, 13*(4), 863-889. https://doi.org/10.1007/s10763-013-9501-1

Royer, J. M. (1979). Theories of the transfer of learning. *Educational Psychologist, 14*(1), 53-69. https://doi.org/10.1080/00461527909529207

Royer, J. M., Mestre, J. P., & Dufresne, R. J. (2005). Framing the transfer problem. In J. P. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. vi-xxvi). Information Age Publishing.

Sadler, P. M., Sonnert, G., Coyle, H. P., Cook-Smith, N., & Miller, J. L. (2013). The influence of teachers' knowledge on student learning in middle school physical science classrooms. *American Educational Research Journal*, Article R and other. https://doi.org/10.3102/0002831213477680

Salomon, G., & Perkins, D. N. (1989). Rocky roads to transfer: Rethinking mechanism of a neglected phenomenon. *Educational Psychologist, 24*(2), 113-142. https://doi.org/10.1207/s15326985ep2402_1

Schwartz, D. L., Bransford, J. D., & Sears, D. (2005). Efficiency and innovation in transfer. *Transfer of learning from a modern multidisciplinary perspective*, 1-51.

Schwartz, D. L., Chase, C. C., & Bransford, J. D. (2012). Resisting overzealous transfer: Coordinating previously successful routines with needs for new learning. *Educational Psychologist, 47*(3), 204-214. https://doi.org/10.1080/00461520.2012.696317

Schwartz, D. L., Chase, C. C., Oppezzo, M. A., & Chin, D. B. (2011). Practicing Versus Inventing With Contrasting Cases: The Effects of Telling First on Learning and Transfer. *Journal of Educational Psychology, 103*(4), 759-775.

Schwartz, D. L., & Martin, T. (2004). Inventing to Prepare for Future Learning: The Hidden Efficiency of Encouraging Original Student Production in Statistics Instruction. *Cognition and Instruction, 22*(2), 129-184. https://doi.org/10.1207/s1532690xci2202_1

Schwinger, M., & Stiensmeier-Pelster, J. (2011). Performance-approach and performance-avoidance classroom goals and the adoption of personal achievement goals. *British Journal of Educational Psychology, 81*(4), 680-699. https://doi.org/10.1111/j.2044-8279.2010.02012.x

Science teaching reconsidered a handbook. (1997).Washington, D.C.: National Academy Press.

Shea, P., Gozza-Cohen, M., Uzuner, S., Mehta, R., Valtcheva, A. V., Hayes, S., & Vickers, J. (2011). The Community of Inquiry framework meets the SOLO taxonomy: a process-product model of online learning. *Educational Media International, 48*(2), 101-113. https://doi.org/10.1080/09523987.2011.576514

Shemwell, J. T., Chase, C. C., & Schwartz, D. L. (2015). Seeking the general explanation: A test of inductive activities for learning and transfer. *Journal of research in science teaching, 52*(1), 58-83. https://doi.org/10.1002/tea.21185

Shim, S. S., Cho, Y., & Wang, C. (2013). Classroom goal structures, social achievement goals, and adjustment in middle school. *Learning and Instruction, 23*, 69-77. https://doi.org/http://dx.doi.org/10.1016/j.learninstruc.2012.05.008

Siler, S. A., & Klahr, D. (2016). Effects of terminological concreteness on middle-school students' learning of experimental design. *Journal of Educational Psychology, 108*(4), 547-562. https://doi.org/10.1037/edu0000072

Singley, M. K., & Anderson, J. R. (1989). *The transfer of cognitive skill*.Cambridge, Massachussets, USA: Harvard University Press.

Sisk, V. F., Burgoyne, A. P., Sun, J., Butler, J. L., & Macnamara, B. N. (2018). To what extent and under which circumstances are growth mind-sets important to academic achievement? Two meta-analyses. *Psychological Science, 29*(4), 549-571. https://doi.org/10.1177/0956797617739704

Slavin, R., Drake, C., Hanley, P., & Thurston, A. (2012). Effective programs for elementary science: a best evidence synthesis. *Best Evidence Encyclopaedia*. http://www.bestevidence.org.uk/reviews/primary_science/index.html

Sloutsky, V. M., Kamininski, K., & Heckler, A. F. (2005). the advantage of simple symbols for learning and transfer. *Psychonomic Bulletin and Review, 12*(3), 508-513.

Snoddy, S. P. (2018). *Preventing inert knowledge: Category status promotes spontaneous structure-based retrieval of prior knowledge* (Publication Number 10792540) [M.S., State University of New York at Binghamton]. ProQuest Dissertations & Theses Global. Ann Arbor.

Son, J. Y., & Goldstone, R. L. (2009). Contextualization in perspective. *Cognition and Instruction, 27*(1), 51-89. www.jstor.org/stable/27739901

South Australia. Education, D. (1992). *Attainment levels*.Adelaide]: Adelaide : Education Dept. of South Australia.

Spencer, R. M., & Weisberg, R. W. (1986). Context-dependent effects on analogical transfer [journal article]. *Memory & Cognition, 14*(5), 442-449. https://doi.org/10.3758/bf03197019

Sternberg, R. J., & French, P. A. (1993). Mechanisms of transfer. In D. K. a. S. Detterman, R.J. (Ed.), *Transfer on Trial: Intelligence, Cognition and Instruction* (pp. 25-38). Ablex Publishing Corp.

Stewart, M. (2011). Joined up thinking? Evaluating the use of concept mapping to develop complex system learning. *Assessment & Evaluation in Higher Education, 37*(3), 349-368. https://doi.org/10.1080/02602938.2010.534764

Stockard, J., Wood, T. W., Coughlin, C., & Rasplica Khoury, C. (2018). The effectiveness of direct instruction curricula: A meta-analysis of a half century of research. *Review of Educational Research, 88*(4), 479-507. https://doi.org/10.3102/0034654317751919

Suprapto, N. (2020). Do we experience misconceptions?: an ontological review of misconceptions in science. *Studies in Philosophy of Science and Education, 1*, 50-55.

Sweller, J. (2010, Jun 2010

2014-08-22). Element Interactivity and Intrinsic, Extraneous, and Germane Cognitive Load. *Educational Psychology Review, 22*(2), 123-138. https://doi.org/https://doi.org/10.1007/s10648-010-9128-5

Szekely, L. (1950). Productive processes in learning and thinking. *Acta Psychologica, 7*, 388-407. https://doi.org/https://doi.org/10.1016/0001-6918(50)90026-6

Taatgen, N. A. (2013). The nature and transfer of cognitive skills. *Psychol Rev, 120*(3), 439-471. https://doi.org/10.1037/a0033138

Talanquer, V. (2009). On cognitive constraints and learning progressions: The case of “structure of matter”. *International Journal of Science Education, 31*(15), 2123-2136. https://doi.org/10.1080/09500690802578025

Tapola, A., Jaakkola, T., & Niemivirta, M. (2014). The influence of achievement goal orientations and task concreteness on situational interest. *The Journal of Experimental Education, 82*(4), 455-479. https://doi.org/10.1080/00220973.2013.813370

Thaden-Koch, T. C., Dufresne, R. J., & Mestre, J. P. (2006). Coordination of knowledge in judging animated motion. *Physical Review Special Topics - Physics Education Research, 2*(2), 020107. http://link.aps.org/doi/10.1103/PhysRevSTPER.2.020107

Therrien, W. J., Taylor, J. C., Hosp, J. L., Kaldenberg, E. R., & Gorsh, J. (2011). Science Instruction for Students with Learning Disabilities: A Meta-Analysis. *Learning Disabilities Research & Practice, 26*(4), 188-203. https://doi.org/https://doi.org/10.1111/j.1540-5826.2011.00340.x

Thomas, L. E., & Lleras, A. (2009). Covert shifts of attention function as an implicit aid to insight. *Cognition, 111*(2), 168-174. https://doi.org/10.1016/j.cognition.2009.01.005

Thomas, R., & Mady, C. (2014). Teaching for transfer: insights from theory and practices in primary level French second language classrooms. l. *McGill Journal of Education (Online), 49*(2), 399-416.

Thompson, S., De Bortoli, L and Buckley, S. (2013). *PISA 2012: How Australia measures up*. A. C. f. E. R. Ltd. http://www.acer.edu.au/documents/PISA-2012-Report.pdf

Thompson, S., Hillman, K and Wernert, N, Schmid, M, Buckley, S, Munene, A. (2012). *Monitoring Australian Year 4 student achievement internationally:TIMSS 2011*. A. C. f. E. R. Ltd. http://www.acer.edu.au/files/TIMSS-PIRLS_Monitoring-Australian-Year-4-Student-Achievement.pdf

Thorndike, E. L. (1903). The influence of special forms of training on more general abilities. In *Educational Psychology*. New York Teachers College.

Thorndike, E. L. (1924). Mental discipline in high school studies. *Journal of Educational Psychology, 15*(1), 1-22.

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. *Psychological Review., 8*(3), 247-261.

Tonhauser, C., & Laura, B. (2016). Determinants of transfer of training: A comprehensive literature review. *International Journal for Research in Vocational Education and Training, 3*(2), 127-165. https://doi.org/10.13152/IJRVET.3.2.4

Transfer of Learning from a Modern Multidisciplinary Perspective. (2005). (J. P. Mestre, Ed.).Greenwith, U.S.A.: Information Age Publishing.

Trenholm, S. (2021). Media effects accompanying the use of recorded lecture videos in undergraduate mathematics instruction*. *International Journal of Mathematical Education in Science and Technology*, 1-29. https://doi.org/10.1080/0020739X.2021.1930221

Tytler, R. (2019). *Inquiry vs direct teaching for interdisciplinary STEM*. Deakin University, STEME Research Group. Retrieved 11 August 2021 from https://deakinsteme.org/blog/inquiry-vs-direct-teaching-for-interdisciplinary-stem/

Tzohar-Rozen, M., & Kramarski, B. (2017). Metacognition and meta-affect in young students: Does it make a difference in mathematical problem solving? *Teachers College Record, 119*(13).

van den Berg, R. G. (2020). *Effect size - a quick guide*. Retrieved 17/01/2022 from https://www.spss-tutorials.com/effect-size/

van Gog, T., Paas, F., & van Merriënboer, J. J. (2004, Jan 2004

2014-08-09). Process-Oriented Worked Examples: Improving Transfer Performance Through Enhanced Understanding. *Instructional Science, 32*(1-2), 83-98. https://doi.org/https://doi.org/10.1023/B:TRUC.0000021810.70784.b0

Vendetti, M. S., Matlen, B. J., Richland, L. E., & Bunge, S. A. (2015). Analogical reasoning in the classroom: Insights from cognitive science. *Mind, brain and education, 9*(2), 100-106. https://doi.org/10.1111/mbe.12080

Verkade, H., Mulhern, T. D., Lodge, J., Elliott, K., Cropper, S., Rubinstein, B., Horton, A., Elliott, C., Espinsos, A., Dooley, L., Frankland, S., Mulder, R., & Livett, M. (2017). *Misconceptions as a trigger for enhancing student learning in higher education.* (Vol. 1).Melbourne, Australia: The University of Melbourne. https://minerva-access.unimelb.edu.au/handle/11343/197958

Vermeulen, R. C. M. (2002). Narrowing the transfer gap: the advantages of "as if" situations in training. *Journal of European Industrial Training, 26*(8), 366-374. https://doi.org/10.1108/03090590210444946

Vogelaar, B., & Resing, W. C. M. (2018). Changes over time and transfer of analogy-problem solving of gifted and non-gifted children in a dynamic testing setting. *Educational Psychology, 38*(7), 898-914. https://doi.org/10.1080/01443410.2017.1409886

Wang, Q., & Ng, F. F.-Y. (2012). Chinese students' implicit theories of intelligence and school performance: Implications for their approach to schoolwork. *Personality and Individual Differences, 52*(8), 930-935. https://doi.org/http://dx.doi.org/10.1016/j.paid.2012.01.024

Wang, Z., Ardasheva, Y., & Lin, L. (2021). Does high perceptual load assist in reducing the seductive details effect? *Educational Psychology, 41*(1), 25-44. https://doi.org/10.1080/01443410.2019.1686465

Warshauer, H. K. (2015). Productive struggle in middle school mathematics classrooms [journal article]. *Journal of Mathematics Teacher Education, 18*(4), 375-400. https://doi.org/10.1007/s10857-014-9286-3

Watts, T. W., Clements, D. H., Sarama, J., Wolfe, C. B., Spitler, M. E., & Bailey, D. H. (2017). Does early mathematics intervention change the processes underlying children's learning? *Journal* *of Research on Educational Effectiveness, 10*(1), 96-115. https://doi.org/10.1080/19345747.2016.1204640

Webb, N. L. (1997). *Criteria for alignment of expectations and assessments in mathematics and science education* (Research Monograph, Issue. C. o. C. S. S. Officers & A. Publications.

Webb, N. L. (2002). *Depth of knowledge levels for four content areas.* Wisconsin Centrefor Education Research, University of Wisconsin-Madison.

Webb, N. L. (2007). Issues related to judging the alignment of curriculum standards and assessments. *Applied Measurement in Education, 20*(1), 7-25. https://doi.org/10.1080/08957340709336728

Westwood, P. (2005). *Spelling. Approaches to teaching and assessment - Second edition*.Melbourne, Australia: ACER Press.

Whittington, C. (1986). Literature review: Transfer of learning in social work education. *The British Journal of Social Work, 16*(5), 571-577. www.jstor.org/stable/23705650

Wiliam, D. (2010). Episode 2. *The classroom experiment*.

Wiliam, D. (2018). *Embedded formative assessment* (Second edition. ed.) Bloomington, Indiana : Solution Tree Press.

Wolfe, C. R., Reyna, V. F., & Sears, D. (2005). Fuzzy-trace theory: Implications for transfer in teaching and learning. In J. P. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. 53-88). Information Age Publishing.

Woltz, D. J., Gardner, M. K., & Gyll, S. P. (2000, 9//). The role of attention processes in near transfer of cognitive skills. *Learning and Individual Differences, 12*(3), 209-251. https://doi.org/http://dx.doi.org/10.1016/S1041-6080(01)00038-3

Woodworth, R. S. (1972). *Woodworth & Schlosberg's Experimental psychology* (3d ed. [by] J. W. Kling & Lorrin A. Riggs and seventeen contributors. ed.).London: London, Methuen.

Woodworth, R. S., & Thorndike, E. L. (1901). The influence of improvement in one mental function upon the efficiency of other functions. (I). *Psychological Review, 8*(3), 247-261. https://doi.org/10.1037/h0074898

Woolf, S. H. (2008). The meaning of translational research and why It matters. *JAMA, 299*(2), 211-213. https://doi.org/10.1001/jama.2007.26

Wu, Y.-J., Carstensen, C. H., & Lee, J. (2020, 2020/05/27). A new perspective on memorization practices among East Asian students based on PISA 2012. *Educational Psychology, 40*(5), 643-662. https://doi.org/10.1080/01443410.2019.1648766

Yan, Z., Brown, G. T. L., Lee, J. C.-K., & Qiu, X.-L. (2020, 2020/04/20). Student self-assessment: why do they do it? *Educational Psychology, 40*(4), 509-532. https://doi.org/10.1080/01443410.2019.1672038

Yang, Y.-T. C. (2012, 11//). Cultivating critical thinkers: Exploring transfer of learning from pre-service teacher training to classroom practice. *Teaching and Teacher Education, 28*(8), 1116-1130. https://doi.org/http://dx.doi.org/10.1016/j.tate.2012.06.007

Yang, Z.-k., Wang, M., Cheng, H. N. H., Liu, S.-y., Liu, L., & Chan, T.-W. (2016, 2016/04/01). The effects of learning from correct and erroneous examples in individual and collaborative settings. *The Asia-Pacific Education Researcher, 25*(2), 219-227. https://doi.org/10.1007/s40299-015-0253-2

Yelon, S. (1992). M.A.S.S.: A model for producing transfer. *Performance Improvement Quarterly, 5*(2), 13-23. https://doi.org/10.1111/j.1937-8327.1992.tb00542.x

Zepeda, C. D., Richey, J. E., Ronevich, P., & Nokes-Malach, T. J. (2015). Direct instruction of metacognition benefits adolescent science learning, transfer, and motivation: an in vivo study. *Journal of Educational Psychology, 107*(4), 954-970.

Zhang, D., Koda, K., & Leong, C. K. (2016, 2016/03/01). Morphological awareness and bilingual word learning: a longitudinal structural equation modeling study. *Reading and Writing, 29*(3), 383-407. https://doi.org/10.1007/s11145-015-9603-y

Zu, T., Munsell, J., & Rebello, N. S. (2019, 01/10/). Comparing retrieval-based practice and peer instruction in physics learning. *Physical Review Physics Education Research, 15*(1), 010105. https://doi.org/10.1103/PhysRevPhysEducRes.15.010105

Zvoch, K., Holveck, S., & Porter, L. (2021). Teaching for conceptual change in a density unit provided to seventh graders: a comparison of teacher- and student-centered approaches. *Research in Science Education, 51*(5), 1395-1421. https://doi.org/10.1007/s11165-019-09907-8