CORA Cork Open Research Archive
Cartlann Taighde Oscailte Chorcaí

Title	An investigation of the development and evaluation of online approaches for improved kinaesthetic learning in science
Authors	Scanlan, Anna M.
Publication date	2023
Original Citation	Scanlan, A. 2023. An investigation of the development and evaluation of online approaches for improved kinaesthetic learning in science. PhD Thesis, University College Cork.
Type of publication	Doctoral thesis
Rights	© 2023, Anna Scanlan. - https://creativecommons.org/licenses/by-nc-sa/4.0/
Download date	2026-11-16 05:09:21
Item downloaded from	https://hdl.handle.net/10468/15353



UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

Ollscoil na hÉireann, Corcaigh

National University of Ireland, Cork



An Investigation of the Development and Evaluation of Online Approaches for Improved Kinaesthetic Learning in Science

Thesis presented by

Anna Scanlan, BSc (Hons)

0000-0002-9923-9139

for the degree of

Doctor of Philosophy

University College Cork

School of Biochemistry and Cell Biology

Head of School/Department: Prof. Justin McCarthy

Supervisor: Prof. Tommie McCarthy

School of Education

Head of School/Department: Prof. Nicola Ingram

Supervisor: Dr. Declan Kennedy

2023

Table of contents

Table of Contents ii
List of Tables viii
List of Figures ix
List of Abbreviations xii
List of Appendices xv
Declaration xvii
Acknowledgements xviii
Public Communication xix
Abstract xx

CHAPTER 1 1
INTRODUCTION
1.1 Thesis statement and hypothesis 1
1.2 The science of learning and the rise of online media 1
1.3 Biological underpinnings of learning 2
1.4 Kinaesthetic learning (KL) 3
1.5 Current research for kinaesthetic learning with molecular science 5
1.6 Aims and Objectives 7
1.7 Main Research Question 7

CHAPTER 2 9
LITERATURE REVIEW
2.1 The development of learning styles and modalities 9
2.1.1 The use of digital technologies for visualising science 15
2.1.2 The neuroscience of learning 21
2.1.3 Learning through movement 24
2.1.4 Recall, technology and the brain 26
2.1.5 Understanding mirror neurons and motor imagery for KL 28
2.1.6 Appraisal of e-learning strategies for KL science lesson content 31
2.1.7 Review discussion 34
2.2 Thesis proposal 35

CHAPTER 3 36

RATIONALE FOR KL LESSON DESIGN, DEVELOPMENT AND USE

3.1 Introduction 36

3.1.1 Motivation 36

3.2 Overview of the high-stakes assessment model and need for a KL approach .. 38

3.2.1 The Irish context 38

3.2.2 The international context 39

3.2.3 Factors perpetuating the use of high-stakes exams 42

3.2.4 Student perceptions affect academic performance 43

3.2.5 Assessing online learning 45

3.2.6 Aligning evidence-based learning approaches to a kinaesthetic learning and assessment model 47

3.3 Methods: Designing the KL Lessons 47

3.3.1 Evaluation criteria for developing the KLS framework 47

3.3.2 Testing the KLS for realistic application in science learning 50

3.4 Materials 57

3.4.1 The KLS Lac Operon lesson layout 57

3.4.2 KLS animated video 60

3.4.3 KLS DNA Research Lesson 62

3.4.4 KLS Science Taster Lesson 64

3.5 Designing the KLS groups 66

i. Unguided Assembly 66

ii. Guided Assembly 68

iii. Mental Assembly 69

iv. Question Guided Recall 70

v. Free Recall 70

vi. Neutral 71

3.6 Learning Outcomes for the three KLS lessons 75

3.7 Predicted Impact 78

3.7.1 Assessment of the KLS framework 79

3.8 Summary 80

CHAPTER 4 82
RESEARCH METHODOLOGY
4.1 Introduction 82
4.1.1 Aims of Study 82

CHAPTER 5 85
PILOT STUDIES
5.1 Introduction 85
5.2 Pilot Study toward developing an effective online kinaesthetic interaction model 85
5.2.1 Experiment 1 Study Objectives 85
5.2.2 Stages of Research and Design 86
5.2.3 Procedure 89
5.2.4 Methodology of Analysis of Results 91
5.2.5 Experiment 1 Results 93
5.2.6 Experiment 1 Discussion 97
5.3 Pilot Study on delivery of an online kinaesthetic assembly model 100
5.3.1 Experiment 2 Study Objectives 100
5.3.2 Stages of Research and Design 101
5.3.3 Procedure 106
5.3.4 Methodology of Analysis of Results 107
5.3.5 Experiment 2 Results 107
5.3.6 Experiment 2 Discussion 117
5.4 Pilot Study investigating the dual aspect of kinaesthetic assembly 120
5.4.1 Experiment 3 Study Objectives 120
5.4.2 Stages of Research and Design 121
5.4.3 Procedure 125
5.4.4 Methodology of Analysis of Results 127
5.4.5 Experiment 3 Results 127
5.4.6 Experiment 3 Discussion 127

CHAPTER 6 129
EXPERIMENT 4
6. Two timepoint KLS study of KL assembly techniques vs. question guided recall of notetaking online 129
6.1 Experiment 4 Study Objectives 129
6.2 Stages of Research and Design 130
6.3 Study Conditions 132
6.4 Procedure 133
6.5 Methodology of Analysis of Results 134
6.6 Experiment 6 Results 136
6.7 Experiment 6 Discussion 140
6.8 Limitation of Results 144

CHAPTER 7 149
EXPERIMENT 5
7. Two timepoint KLS sub-study comparing a KL assembly technique to a KL static disassembled technique 149
7.1 Experiment 5 Study Objectives 149
7.2 Stages of Research and Design 150
7.3 Procedure 151
7.4 Methodology of Analysis of Results 154
7.5 Experiment 5 Results 155
7.6 Experiment 5 Discussion 157

CHAPTER 8 159
EXPERIMENT 6
8. Two timepoint KLS study of a KL assembly technique, a free recall note-taking technique and a ‘cramming’ technique 159
8.1 Experiment 6 Study Objectives 159
8.2 Stages of Research and Design 160
8.3 Procedure 161
8.4 Methodology of Analysis of Results 161
8.5 Experiment 6 Results 162
8.6 Experiment 6 Discussion 164

8.7 Limitations of the Study 165

CHAPTER 9 167

EXPERIMENT 7

9. Assessing the scalability and expandability of the KLS in collaboration with a selection of Irish secondary schools 167

9.1 Experiment 7 Study Objectives 167

9.2 Stages of Research and Design 168

9.3 Procedure 170

9.4 Methodology of Analysis of Results 172

9.5 Experiment 7 Results 173

9.6 Experiment 7 Discussion 175

9.7 Limitations of the Study 176

CHAPTER 10 180

EXPERIMENT 8

10. Sub-study challenging the KLS with a short, intensely complex science lesson amongst postgraduates from multiple disciplines 178

10.1 Experiment 8 Study Objectives 178

10.2 Stages of Research and Design 179

10.3 Procedure 179

10.4 Methodology of Analysis of Results 181

10.5 Experiment 8 Results 181

10.6 Experiment 8 Discussion 183

CHAPTER 11 185

SUMMARY

11. Summary of Methodology and Results from all 8 Experiments 185

CHAPTER 12 191

CONCLUSIONS AND RECOMMENDATIONS

12. Introduction 191

12.1 Main research findings 192

12.1.1 Examination of Current Online KL 192

12.1.2 Translating KL to an Online Learning Approach for Science 193
12.1.3 Critical Appraisal of the Literature 197
12.2 The Development of Novel Online KL Approaches 198
12.3 Empirical Evaluation of the Efficacy of KL Approaches 200
12.3.1 The Qualitative Data *201*
12.3.2 The Quantitative Data *204*
12.4 Validity in Testing 205
12.5 Limitations of the Research Study 206
12.6 Impact of Emergent Developments 210
12.7 Research Impact for Teaching and Learning 211
12.8 A Summary of Recommendations 214
12.9 Closing Remarks 215

REFERENCES 217
APPENDICES 232

List of Tables

Table 1: EBSCO Database Results Using Terms: 'Kinaesthetic or Kinesthetic' AND 'Biochemistry or Molecular Biology' 6
Table 2.1**:** Prominent Learning Theories from the Early 20th Century Onwards..... 10
Table 2.2**:** Established E-learning Guidelines for the Development of Online Lessons 32
Table 3.1**:** Evaluating the KLS 48
Table 3.2: Software Considered for Implementation of the KLS 52
Table 3.3**:** Concept Table for the KLS Lac Operon lesson 55
Table 3.4**:** Learning Outcomes for the Lac Operon Lesson 76
Table 3.5**:** Learning Outcomes in relation to the DNA Research lesson 77
Table 3.6: Learning Outcomes in relation to the Science Taster lesson..... 78
Table 5.1**:** Check for Constructive Alignment of Lac Operon Lesson Exp. 1..... 86
Table 5.2**:** Check for Constructive Alignment of Lac Operon Lesson Exp. 2..... 101
Table 5.3**:** Check for Constructive Alignment of Lac Operon Lesson Exp. 3..... 120
Table 6.1**:** Check for Constructive Alignment of Lac Operon Lesson Experiment 129
Table 6.2**:** Demographic Balance of Groups for Experiment 4..... 132
Table 7.1**:** Check for Constructive Alignment of Lac Operon Lesson Experiment 5 149
Table 7.2**:** Demographic Balance of Groups for Experiment 5..... 150
Table 7.3**:** Marking Scheme for Multi-Select Questions 153
Table 8.1**:** Check for Constructive Alignment of Lac Operon Lesson Experiment 6 159
Table 8.2**:** Demographic Balance of Groups for Experiment 6, Part I..... 160
Table 8.3**:** Demographic Balance of Groups for Experiment 6, Part II 161
Table 9**:** Check for Constructive Alignment of the DNA Research Lesson..... 167
Table 10**:** Check for Constructive Alignment of the Salmonella Science Taster Lesson..... 178
Table 11**:** Summary overview of all KLS experiments' results 186

List of Figures

Figure 2.1 Kolb's Experiential Learning Cycle 11
Figure 2.2 Anatomage Table 18
Figure 2.3 The Lac Operon Gene Regulation System 19
Figure 2.4 Perspective Effect 29
Figure 2.5 Homunculus 30
Figure 3.1 Bloom's Taxonomy 48
Figure 3.2 Practice PowerPoint Instruction Slides 58
Figure 3.3 Sample PowerPoint slide from the Lac Operon lesson 59
Figure 3.4 Workflow for designing and creating KLS lesson videos 62
Figure 3.5 Sample PowerPoint slide from the DNA Research lesson 64
Figure 3.6 Sample PowerPoint slide from Science Taster lesson 65
Figure 3.7 (a) Sample Unguided Assembly task from Lac Operon lesson 67
Figure 3.7 (b) Sample Unguided Assembly task from DNA Research lesson 67
Figure 3.7 (c) Sample Unguided Assembly task from Science Taster lesson 67
Figure 3.8 (a) Sample Guided Assembly task slide from Lac Operon lesson 68
Figure 3.8 (b) Sample Guided Assembly task slide from DNA Research lesson 68
Figure 3.8 (c) Sample Guided Assembly task slide from Science Taster lesson 69
Figure 3.9 (a) Sample Mental Assembly task from Lac Operon lesson 70
Figure 3.9 (b) Sample Mental Assembly task from DNA Research lesson 70
Figure 3.9 (c) Sample Mental Assembly task from Science Taster lesson 71
Figure 3.10 Sample Question Guided Recall task from Lac Operon lesson 71
Figure 3.11 Sample Free Recall task slide which was almost identical for all lessons 71
Figure 3.12 (a) Sample Neutral instruction slide from Lac Operon lesson 72
Figure 3.12 (b) Sample Neutral instruction slide from DNA Research lesson 72
Figure 3.12 (c) Sample Neutral instruction slide from Science Taster lesson 73
Figure 4.1 Experiment and Methodology Flowcharts 84
Figure 5.1 Operation Flow Chart for Student Communication and Recruitment 87
Figure 5.2 Sample of Two KL Lesson Slides from Pilot Study 1 90
Figure 5.3 Comparison of Mean Grade for the KLS Test Condition vs. Control 94
Figure 5.4 Thematic Framework for Experiment 1 96
Figure 5.5 SCIOPTLE Instagram Theme Titles 102

Figure 5.6 Experiment 2 Animated Lac Operon Video Lesson 103
Figure 5.7 Experiment 2 Sample Animated Instructions Slide 104
Figure 5.8 Experiment 2 Sample Lesson Notes Slide for Control Group 104
Figure 5.9 Experiment 3 Sample Slides 107
Figure 5.10 Student 1 Unguided Assembly Task Slides 5, 6 and 7 Completed Incorrectly 114
5.10.i. Slide Lesson 5 and Task Slide 111
5.10.ii Slide Lesson 6 and Task Slide 112
5.10.iii. Slide Lesson 7 and Task Slide 113
Figure 5.11 Student 2 Unguided Assembly Task Slides 5, 6 and 7 Completed Correctly 116
5.11.i. Task Slide 5 114
5.11.ii Task Slide 6 114
5.11.iii. Task Slide 7 115
Figure 5.12 Student 3 Incomplete and Incorrect Unguided Assembly Task Slides 5, 6 and 7 116
5.12.i. Task Slide 5 115
5.12.ii Task Slide 6 116
5.12.iii Task Slide 7 116
Figure 5.13 Experiment 3 Sample Slides 123
5.13.i Sample Lesson Notes Slide 122
5.13.ii Sample KLSA (Unguided Assembly) Task Slide 122
5.13.iii Sample KLSM (Guided Assembly) Task Slide 122
5.13.iv Sample KLSR (Question Guided Recall) Task Slides 123
Figure 5.14 Experiment 3 Time Options 123
Figure 5.15 Sample Title Slide 124
Figure 6.1 G*Power Analysis for Experiment 4 131
Figure 6.2 (A) Experiment 4 Comparison of Mean Grade for Unguided Assembly vs. Guided Assembly vs. Question Guided Recall 137
Figure 6.2 (B) Experiment 4 Comparison of Mean Grade for Unguided Assembly vs. Guided Assembly vs. Question Guided Recall 138
Figure 6.3 (A) Initial Pearson Correlation Analysis of Timepoint 1 139
Figure 6.3 (B) Initial Pearson Correlation Analysis of Timepoint 2 139

Figure 6.4 (A) Second Pearson Correlation Analysis with Outlier Removed 140
Figure 6.4 (B) Second Pearson Correlation Analysis of Timepoint 2 with Outlier Removed 140
Figure 6.5 Final slides returned from students in (A) Question Guided Recall, (B) Guided Assembly and (C) Unguided Assembly 145
Figure 6.6 Individual question analysis for timepoint 1, Experiment 4 146
Figure 7 Experiment 5 Comparison of mean grade for Unguided Assembly vs. Mental Assembly 156
Figure 8 Experiment 6 Comparison of mean grade for Unguided Assembly vs. Free Recall vs. Neutral 163
Figure 9.1 Infographic for Secondary Schools 171
Figure 9.2 Experiment 7 Comparison of Secondary School Study Results 175
Figure 10.1 Experiment 8 Comparison of Postgraduate Study Results 183

List of Abbreviations

ALPS	Accelerated Learning in the Primary School
ANOVA	Analysis of Variance
AP	Action Potentials
APA	American Psychological Association
BCC	Blind Carbon Copy
cAMP	Cyclic Adenosine Monophosphate
CAO	Central Applications Office
CAP	Catabolite Activator Protein
cf	Cross Reference
CI	Confidence Interval
CNS	Central Nervous System
CSO	Central Statistics Office
CSPE	Civic Social Political Education
CTML	Cognitive Theory of Multimedia Learning
DNA	Deoxyribonucleic Acid
EEG	Electroencephalogram
F	F-statistic
GDPR	General Data Protection Regulation
HEAd'21	International Conference on Higher Education Advances, June 2021
HOCS	Higher Order Cognitive Skills
HSD	Honestly Significant Difference
ICAP	Interactive, Constructive, Active, Passive framework
Inv	Invasion Genes (in *Salmonella*)
JC	Junior Cycle
JEPG	Journal of Experimental Psychology: General
JPJP	Journal of Personality and Social Psychology
KL	Kinaesthetic Learning
KLS	Kinaesthetic Learning System
KLSA	Kinaesthetic Learning System Assembly (early iteration of Unguided Assembly)

KLSM	Kinaesthetic Learning System Movement (early iteration of Guided Assembly)
KLSR	Kinaesthetic Learning System Recall (early iteration of Question Guided Recall)
Lac	Lactose
LC	Leaving Certificate
LOCS	Lower Order Cognitive Skills
LTP	Long-term Potentiation
M	Mean
MBTI	Myers-Briggs Type Indicator test
MCQ	Multiple Choice Questions
Mdn	Median
mRNA	Messenger Ribonucleic Acid
MSQ	Multi-Select Questions
n	Sample
NMDA	N-Methyl-D-Aspartate
NPS	No Prior Science
NUI	National University of Ireland
OECD	Organisation for Economic Co-operation and Development
PNS	Peripheral Nervous System
PPTs	PowerPoints
PS	Prior Science
PS	Psychological Science
r	Pearson's Correlation Coefficient
RCT	Randomised Control Trials
RNA	Ribonucleic Acid
SAQ	Short Answer Questions
SAT	Scholastic Assessment Test
SCIOPTLE	Optimising Learning of Science
SD	Standard Deviation
SMA	Supplementary Motor Area
SPHE	Social Personal and Health Education
SPSS	Statistical Package for the Social Sciences

SREC	Social Research Ethics Committee
STEM	Science, Technology, Engineering, Mathematics
SWR	Siphon Withdrawal Reflex
TREs	Technological Rich Environments
UCC	University College Cork
UDL	Universal Design for Learning
URL	Uniform Resource Locator or web address
VAK	Visual, Aural and Kinaesthetic learning model
VARK	Visual, Aural, Reading/writing and Kinaesthetic learning model
VR	Virtual Reality
ZPD	Zone of Proximal Development

List of Appendices

Appendix A

Figure A.1: Sample Invitation Email 232

Figure A.2: Sample Email Outlining the Bonus for KLS Study Volunteers 234

Figure A.3: Sample Email with Instructions for Participating in Experiment 3 235

Figure A.4: Thank You Email with Request for Feedback 236

Figure A.5: Sample Online Participant Information, Consent Form and Questionnaire 237

Appendix B

Figure B.1: Sample Lac Operon MCQ 242

Figure B.2: Experiment 5 Timepoint Quiz 247

Figure B.3: Experiment 2 Thematic Framework 253

B.3.i. Control Group Feedback 253

B.3.ii Lac Test Interaction Group Feedback 254

Appendix C

Figure C.1: Instructional Email to Secondary Schools who Agreed to Participate 255

Figure C.2: Secondary School Pack Containing the Invitation, Information, Consent and Assent Forms for Participation in the KLS Study 257

Figure C.3: Link to Secondary School MCQ 262

Figure C.4: Thank You Email to Teachers who Facilitated the Study 263

Appendix D

Figure D.1: Email to postgrad students on acceptance of the study invitation 264

Figure D.2: Science Taster T1 Quiz Link for Experiment 8 266

Appendix E

Table E.1: Experiment 4 SPSS Output Tables

E.1.i. Timepoint 1 data analysis 266

E.1.ii. Timepoint 2 data analysis 267

Table E.2: Experiment 5 SPSS Output Tables

E.2.i. Timepoint 1 data analysis 268

E.2.ii. Timepoint 2 data analysis 269

Table E.3: Experiment 6 SPSS Output Tables

E.3.i. Timepoint 1 data analysis 270

E.3.ii. Timepoint 2 data analysis 270

Table E.4: Experiment 7 Secondary Schools SPSS Output Tables

E.4.i. Timepoint 1 data analysis 272

E.4.ii. Timepoint 2 data analysis 272

Table E.5: Experiment 8 Postgraduate SPSS Output Tables

E.5.i. Timepoint 1 data analysis 274

E.5.ii. Timepoint 2 data analysis 277

Appendix F

Figure F.1 Flowchart for Implementing Two Timepoint Study 279

Appendix G: The suitability of KLS as a Qualitative Research Project..... 280

Declaration

This is to certify that the work I am submitting is my own and has not been submitted for another degree, either at University College Cork or elsewhere. All external references and sources are clearly acknowledged and identified within the contents. I have read and understood the regulations of University College Cork concerning plagiarism.

Signed…….Anna Scanlan……

Anna Scanlan, 2023

Acknowledgements

I would like to thank my supervisors Prof. Tommie McCarthy and Dr. Declan Kennedy for their support and guidance throughout this thesis research and the School of Biochemistry and Cell Biology for providing a research stipend.

A debt of gratitude is owed to all students and secondary school teachers who volunteered their time to participate in the kinaesthetic research lessons and without whom none of this research would have been possible – thank you all.

A big thank you is due to friends and colleagues who were always ready to offer words of encouragement or advice. Your kindness and humour meant everything.

Most importantly, I would like to thank my wonderful family who for the past ten years, have made numerous sacrifices to help me progress in education. At times when I wavered as a first-year undergraduate, my son Seán (then 11, now 20) pointed out, *"Then all our early mornings will have been for nothing"!*

"For the things we have to learn before we can do them, we learn by doing them"
— Aristotle

Public Communication of Thesis

A digital poster outlining the conception, rationale and design for the KLS framework was displayed and discussed amongst peers at the 28th ICDE World Conference on Online Learning, Dublin, in November 2019 (view via the link: https://tinyurl.com/WCOLposter2019). This conference is the largest and most notable international conference for digital learning. The poster was evaluated by an international review panel and deemed to show *"Evidence of alignment, contribution to new knowledge, links between theory, research and practice, and overall coherence."*

A proposal of this research was shortlisted for the NUI Dr Mary L Thornton Scholarship and Prize in Education in 2019. Following an interview by a panel of Professors from the five different National Universities of Ireland (NUI), this research was awarded second place and received the NUI Dr Mary L Thornton Prize in Education in November of that year.

A conference paper titled *'Development and Evaluation of Online Approaches for Improved Kinaesthetic Learning in Science'* was peer reviewed and published open access by the *7th International Conference on Higher Education Advances* (HEAd'21) in June 2021. This paper outlined the development and implementation of interactive assembly lessons in PowerPoint arising from the KLS pilot studies. A printed poster outlining the scalability of the KLS toward learning science from secondary school up to postgraduate level, was presented at the College of Medicine and Health's Learning and Teaching Showcase (UCC) in June 2022 (view via the link: https://tinyurl.com/COMHposter2022).

Abstract

Kinaesthetic learning approaches (KL) offer great potential to enhance learning in the advanced molecular sciences. However, online KL remains under-researched and poorly implemented on affordable, scalable platforms. Furthermore, there appears to be a disconnect between the fields of education psychology and neuroscience when discussing kinaesthetic techniques. This research connects what is known from both disciplines to provide a coherent overview of what constitutes kinaesthetic learning.

Here, an online KL assembly model is presented which proved effective for learning advanced molecular science topics as exemplified by three different lessons: the Lac Operon gene regulation system in *E. coli,* DNA transcription and translation, and *Salmonella* virulence factors. A mixed-methods study was conducted including three pilot studies, three randomised control trials and two sub-studies. Study participants included over 100 students from a variety of secondary schools (typically aged 16-19 years), over 250 first-year undergraduate science and medicine students, and 18 postgraduate students from both science and non-science disciplines.

Topics were chosen for which each cohort would have little to no prior learning. Results show that KL assembly was at least as effective and, in some instances better than, some top learning strategies identified in education psychology namely, computer notetaking (Trafton & Trickett, 2001; Bui et al., 2012; Chi & Wylie, 2014) and retrieval-practice (O'Day & Karpicke, 2021). KL assembly involving both movement and recall was most effective overall for long-term learning retention, and for learning science material that is represented in a complex graphical and text format.

Keywords*:* kinaesthetic, molecular science, online learning, education psychology, cognitive neuroscience, online learning, e-learning, science education.

CHAPTER 1

INTRODUCTION

1.1 Thesis statement and hypothesis

The potential for digital technologies to enhance learning for advanced molecular science through an online kinaesthetic interaction has not been utilised effectively on affordable platforms or for modifiable formats. Furthermore, while instructional design practices have improved the representation of material online through frameworks such as Universal Design for Learning (UDL) (CAST, 2018), there is little to guide the specific translation of traditionally offline kinaesthetic approaches into an online format applicable to learning complex molecular science.

The hypothesis formed was that online kinaesthetic learning (KL) approaches would significantly enhance learning for students by helping them to visualise and interact with lesson content, leading to a more immediate grasp of difficult science concepts, better long-term learning retention and deeper understanding of the topic. Chapter 1 introduces the background and context for the thesis, explores the literature to understand the research problem and concludes with the research aims, objectives and action plan.

1.2 The science of learning and the rise of online media

The science of learning is concerned with how the best learning can be achieved for people of all ages, backgrounds or disciplines through research of instruction and assessment methods (Clark & Mayer R, 2008; Mayer R, 2018). In terms of the evolution of learning, we have entered a new era in which digital technology can provide a powerful means of delivering educational content on a scale previously impossible. While screen technology is widely regarded as a valuable addition to learning, we are on the cusp of its development and longitudinal studies on the long-term effects of its use are limited (Kumar, Sarkar, Davis, Morphet, Maloney, Ilic & Palermo, 2021). Controversial debates have played out in the literature with contradictory arguments in relation to the neurobiological effects that digital technologies may have on the brain (Greenfield, 2003, 2015; Bell,

Bishop, & Przybylski 2015; Haughton, Aiken & Cheevers, 2015). Carr (2011) argues that computer use has rewired the brain to access information faster, but not at a deeper intellectual level, by 'skimming' over online content (i.e., content presented on-screen via digital technologies such as laptops, mobile phones, etc.) in preference to reading offline. The European Cooperation in Science and Technology's (2019) *Stavanger Declaration* notes that skimming over reading material with less concentration for the content, was a particular feature associated with digital content, as reported from a meta-study involving over 170,000 participants. Greenfield (2015) reasons that such effects are due to living in a rapidly changing technological environment; because the brain, throughout evolution has adapted to its environment, it may now adapt to interact with technology to the detriment of human interaction.

Nonetheless, the application and use of digital technology is rapidly becoming a fixed feature in learning. Although the traditional teaching style of visual and verbal dissemination of knowledge from teacher to student still predominates, a major shift towards blended and asynchronous online learning has occurred, propelled by the recent Covid-19 pandemic (Weishaar, 2021). In light of the growing trend towards large scale digital technology use, it is important to consider the long-term successful and optimal integration of online technology into education. The merging of such technology with curriculum should be founded on sound theory and rigorous methodological studies (Clark & Mayer, 2008; Sankey, Birch & Gardiner, 2011; Shute, Leighton, Jang & Chu, 2016).

1.3 Biological underpinnings of learning

Much of the current research into online/electronic or 'e-learning' relies on psychology theories, with limited input from the fields of neuroscience or biochemistry. Yet, understanding the neuroscience behind learning and executive functions is recognised as important to the future development of improved learning techniques (Mayer R, 2018). The complex structure of the brain relies on the fluent co-ordination of various neural structures within different regions of the nervous system, to integrate and store information being processed from internal and external sensory systems (Kolb & Whishaw, 1996). Evidence from simple animal studies

suggest multiple parts of the nervous system have the capacity to learn (Bédécarrats, Chen, Pearce, Cai & Glanzman, 2018). This implies that diverse neural regions have the ability to develop distinct memories (Kolb & Whishaw, 1996). These areas can be further subdivided to retain memories associated with specific sensory stimuli. For example, the visual system is subdivided to retain memory for shapes, colours and movement, all of which are interlinked with the other vast subdivisions of the nervous system (Kolb & Whishaw, 1996). Sensory axons projecting from sensory organs (skin, eyes, ears, etc.) relay external information from the environment to the brain, in the network known as the somatosensory system (LeDoux, 2008; Squire, Berg, Bloom, Lac, Ghosh & Spitzer, 2012). Subsequent body movement is controlled by motor nerves which run outward, from glutamate activated pyramidal cells in the motor cortex and associated structures of the brain, to the rest of the body. In evolutionary terms, this integration of the cognitive and physical centres of the brain enables a much faster means of processing information to effect learning. For example, consider teaching a student with no prior knowledge of the workings of a standard zip, i.e., how to open and close a zip. One option would be to teach the student via step-by-step written instructions. An alternative would be to demonstrate directly, the set of actions required to open and close the zip. Intuitively, the latter 'learning by doing' or 'kinaesthetic' approach toward learning is a more efficient and intuitive means of communication.

1.4 Kinaesthetic learning (KL)

Kinaesthetic is commonly defined as *"connected with the ability to know where the parts of your body are and how they are moving"* (URL 1). In research however, what constitutes as KL is much broader and more difficult to define. Generally, kinaesthetic learners are recognised as those who use movement or tactile learning through for example, physical activities or trial and error practice (Bolliger & Supanakorn, 2011), role-play and other interactions which help them to experience the concept being learned. As such, KL is an active and immersive process.

Low cognitive engagement with lesson content such as passive reading or passive listening, has led to less learning gains than strategies requiring higher

cognitive skills, such as active engagement through notetaking, analysing, problem solving and interacting with peers to reason and discuss the learning content (Chi & Wylie, 2014; Yogev, Gal, Karger, Facciotti & Igo, 2018). Prior research shows that learning is significantly increased when learning is active (Kolb & Whishaw, 1996; Mayer R, 2003; Chi & Wylie, 2014; Fiorella, van Gog, Hoogerheide & Mayer R, 2017; Fiorella & Mayer R, 2018). The potential of digital technology is beginning to be realised and is acknowledged for augmenting active learning approaches (such as KL) through more visual and dynamic content and to better represent complex lesson material in a manner that supports the mental modelling required for deeper understanding (Seel, 2017; Schneider, Beege, Nebel & Rey, 2018; Xie, Mayer R, Wang, Zhou, 2018). For the sciences, digital technology has enabled the conversion of static texts and graphics into narrated and animated video content, simulations and immersive virtual reality (VR) content to support online, interactive KL. However, the majority of online media and platforms for science are created externally from the classroom and independently of educators, thus limiting the ability of teachers to adapt content to their specific requirements. Furthermore, and with respect to education in the molecular sciences, much of the online KL content created to date has focused on practical aspects such as laboratory techniques and experiments. For this type of KL, students require prior science knowledge to navigate through the steps of a lesson commonly presented as onscreen simulations. In contrast, KL approaches toward teaching the theoretical and foundational concepts that scaffold this prior knowledge are very limited.

Although instructional design practices have improved the representation of material online, there is less guidance available to guide the translation of offline kinaesthetic approaches into an online kinaesthetic format applicable to learning advanced science topics. The use of KL with digital technologies has the potential to bridge this gap. Obstacles toward the development of online interactive approaches, such as KL, include the time and research costs (Gegner, Mackay & Mayer R., 2009), the challenge of scalability and the supporting infrastructure required for lesson delivery through digital means. There is also a translational challenge. It is relatively easy to conceive how a person might adopt KL techniques in tangible, real-life situations by for example, piecing together a circuit board in practice for a job requiring the assembly of circuit boards. Less clear, is how to translate a KL approach to the non-physical online world for learning intangible science content

that is not only difficult to visualise, but which can appear highly unrelatable to our everyday experience of reality. Digital technology can help in this regard in a way that is not possible offline, through the digital illustration of molecules and molecular processes which can then be made dynamic and interactive onscreen. Moveable onscreen content lends itself to creating an online KL approach that may be more applicable than traditional approaches toward learning sub-microscopic, abstract and difficult subjects like molecular science.

1.5 Current research for kinaesthetic learning with molecular science

The early stages of the literature review process which began in 2018, revealed a paucity of research for online kinaesthetic learning in relation to science. Apart from the university's library of databases, many searches were carried out in Google Scholar, PubMed, Marketline, OECD, CSO, Science Direct and more. Multiple variations and combinations of search terms were inputted throughout this research from 2018 onward and included broad terms to begin with such as: tactile, haptic, physical and active learning, hands-on, experiential, life sciences, biology, etc. Numerous irrelevant and somewhat relevant results were whittled down using more specific terms related to kinaesthetic learning and molecular science.

A more recent spot-check for new publications using specific, kinaesthetic-related search terms shows little improvement. In a single timepoint in January 2022, the words 'Kinaesthetic or kinaesthetic' AND 'Biochemistry or molecular biology' were inputted into EBSCO Database for a search across ten databases including: CINAHL Plus with Full Text, Academic Search Complete, British Education Index, Education Full Text (H.W. Wilson), General Science Full Text (H.W. Wilson), GreenFILE, Humanities Full Text (H.W. Wilson), MEDLINE, APA PsycArticles, and APA PsycInfo. When the 'Subject' category was checked to include the option of 'kinaesthetic,' just six results were returned from the date range 1985 - 2021. As can be seen from Table 1, only two of the research titles (Turner, 2016) and (Costabile, 2020), appear somewhat relevant.

Table 1 EBSCO Database Results Using Terms: 'Kinaesthetic or Kinesthetic' AND 'Biochemistry or Molecular Biology'

Source	Research Title	Study Focus
Campbell, Stenstrom & Bertrand, 1985	Systematic changes in perceptual reactance induced by physical fitness training.	Study of an 8-week physical fitness program in which participants enrolled in meditation and yoga.
Mason, Pluchino & Ariasi, 2014	Reading information about a scientific phenomenon on webpages varying for reliability: an eye movement analysis.	Study using eye tracking to investigate the visual attention students paid to content across 4 webpages covering the central dogma of molecular science.
Montrieux, Vangestel, Raes, Matthys & Schellens, 2015	Blending Face-to-Face Higher Education with Web-Based Lectures: Comparing Different Didactical Application Scenarios	Study applying web-based lectures in 3 different scenarios: as prep for practical exercises, as repetition of course sections, and as a course extension.
Voltzow, 2016	Replication Rhumba & Translation Tango: Active Learning Exercises for Introductory Biology	Students used their bodies in exercises to model DNA replication to gain more spatial and temporal awareness of molecular processes.
Turner, 2016	A Cost-Effective Physical Modeling Exercise To Develop Students' Understanding of Covalent Bonding	Study using pipe cleaners and plastic beads to model covalent bonding; was limited to that topic and method.
Costabile, 2020	Using online simulations to teach biochemistry laboratory content during COVID-19.	Study of 5 simulations on basic laboratory skills such as setting a pipette, reading, math skills and performing basic biochemistry assays.

Broadening the search to 'kinaesthetic or kinesthetic learning' AND 'biochemistry or molecular biology or molecular science or biomolecular science' narrowed results to the two papers (Turner, 2016) and (Costabile, 2020) already discussed. Changing the search for 'kinaesthetic or kinaesthetic learning' to 'online kinaesthetic learning' while retaining the science terms, returned zero results. Finally, removing the science terms but leaving 'online kinaesthetic learning' in the search returned two results, one of which was a qualitative study using questionnaires to evaluate student perceptions of learning and the second, measured learning outcomes across learning styles and modal preferences. Adjusting the search terms to include 'online learning or e-learning or online interactive learning' AND 'kinaesthetic or kinesthetic or learn by doing or physical practice' AND 'Biochemistry or molecular biology or life sciences or biomolecular science,' from the (automatic) date range 1997-2021 returned 22 results which were less relevant again and included, for example, '*2019 AWARDS of EXCELLENCE TECH & LEARNING,*' and '*In Their Own Words: Alan Covich*,' recognising scientists who

have made important contributions to their fields. Hence, early in the literature review process, to source papers that would serve to inform our research, the search was turned instead toward best-practice guidelines for e-learning from the field of education psychology.

1.6 Aims and Objectives

The aim of this research was to examine current online kinaesthetic approaches for learning in the molecular sciences, review the context in which they were being used and to design and develop an online kinaesthetic approach for application to an advanced molecular science topic(s). The main objectives focused on the identification, design and development of novel approaches that would facilitate online KL for molecular science and evaluate their efficacy in learners.

1.7 Main Research Question

The main research question for this thesis study may be expressed as follows: How can online approaches for improved KL be applied to molecular science for learning at the higher levels of academia? The sub-research questions arising from this key question are:

1. What are KL approaches and how well have they translated to online learning platforms?
2. Why should online KL approaches for science be considered from an education psychology and neuroscience perspective?
3. Is it possible to develop a framework for designing, developing and implementing KL approaches on affordable online platforms?
4. Can students realistically apply online KL approaches to learn substantial molecular science content?
5. Are online KL approaches scalable to different knowledge levels and expandable for use to other disciplines and/or locations?
6. Might online KL approaches provide an alternative format for self-paced, self-directed, self-assessed learning?

7. Does empirical testing reveal any effect on learning when an online KL approach is employed?

CHAPTER 2

LITERATURE REVIEW

2.1 The development of learning styles and modalities

From the beginning of the 20th Century, interest grew in the psychological aspects of learning, largely based on comparative lab animal studies which highlighted the role reward and punishment play in motivating learned behaviours (McLeod, 2017a, 2018a; Mayer R, 2018). As human cognitive processes are more advanced, generalising this research to children in a classroom setting fell short in explaining the more complex thinking required for human learning (Clark & Mayer R, 2008; Mayer R, 2003, 2018).

Attention switched later in the 20th Century from behaviourist theories to cognitive theories of learning (McLeod, 2015; Mayer R, 2018). Strategies adopted by people to facilitate learning became the focus of research from the 1940s onward and theories on learning abounded. Prominent learning theories developed are outlined in Table 2.1. In addition, more than 60 learning style models have been proposed including, the Myers-Briggs Type Indicator test (MBTI), Felder–Silverman, Dunn and Dunn, Honey and Mumford, Herrmann Brain Dominance Instrument and more (Baskaran, Applanaidu, Ng, & Ramakrishnan, 2015). Some of the most persistent learning models referred to in current research include Kolb's '*Learning Style Inventory'* (McLeod, 2017b), (see Figure 2.1) and Fleming's VARK model for visual, aural, reading/writing and kinaesthetic learning (Fleming & Mills, 1992). In David Kolb's experiential learning theory (developed in 1974), four interdependent cycles relate how information is first perceived and understood, followed by how it is actively reflected upon. Progression through all stages of the cycle is seen as necessary for learning and the cycle can be entered at any point (McLeod, 2017b). This model remains a popular reference for engineering education in particular (Ahmed & Opoku, 2021).

Table 2.1 Prominent Learning Theories from the Early 20th Century Onwards

Key learning theorist	Key Findings
	Behaviourism
Ivan Pavlov Classical conditioning	Dogs salivate naturally in response to seeing food. In stimulus response studies, Pavlov trained or 'conditioned' dogs to salivate in response to a bell which signals feeding time. (McLeod, 2018b)
J.B. Watson Behaviourism	External stimuli affect learning, e.g., environment and experiences, and manifest as observable behaviours. (McLeod, 2017a)
B.F. Skinner Operant conditioning	Skinner focused on the role reward and punishment play in learning. Humans are comparable to animals in behaviour in that positive stimuli cause a positive response; negative stimuli cause a negative response. (Wellington, 2000)
	Constructivism
Jean Piaget Cognitive development	Piaget observed the developmental stages of toddlers, helping to establish expected developmental milestones. Children develop an understanding of themselves and their surroundings as brain matures – they are intrinsically motivated to learn. (Wellington, 2000; McLeod, 2019)
Lev Vygotsky Constructivism & Zone of Proximal Development (ZPD)	Human learning strongly affected by language, culture, social role in environment and inter-actions. (McLeod, 2019) ZPD: for progress, learning should be challenged with guidance from the more experienced. Prior knowledge and experiences can be built upon and educators can remove learning supports as the learner progresses to more independence and self-direction. (Wellington, 2000; Gazzaniga (Ed.), 2005)
Jerome Bruner Scaffolding	Scaffolding: active form of learning in which initial reliance on a teacher or instructor becomes less as the learner increases in competency. (Wellington, 2000; Smith, 2002)
	Cognitivism
Jerome Bruner Cognitivism & Process of Education	Unobservable neurobiological processes considered, e.g., memory capacity, attention, mood. Progression of learning should be informed by child's capabilities and the education structure; and new concepts should be revisited to cement learning. (Wellington, 2000; Smith, 2002; McLeod, 2019) Original thoughts can be generated without stimuli, e.g., creativity, predictions, inventions; and interest should motivate learning.
Albert Bandura Social cognitivism	Social cognitivism: self-efficacy motivates active learning and having agency over behaviour during learning helps achieve better outcomes. Learning can be supported by enabling learner to self- evaluate and analyse progression. (McLeod, 2016)
Richard E. Mayer Cognitive load	Cognitive load: new information is stored in short-term working memory before moving to long-term for later recall. If too many inputs overwhelm working memory, information will not reach long-term storage. (Clark & Mayer, 2008; De Jong, 2010)
	Andragogy
Malcolm Knowles Adult learning	Considered formal vs. informal learning environments and found the role of the instructor is important to learning. Adult learning is extrinsically motivated by circumstances, e.g., prior life, education and cultural experiences important in affecting learning in adults and must be considered for course design. Adults prefer more collaborative and autonomous learning. (Pappas, 2013)

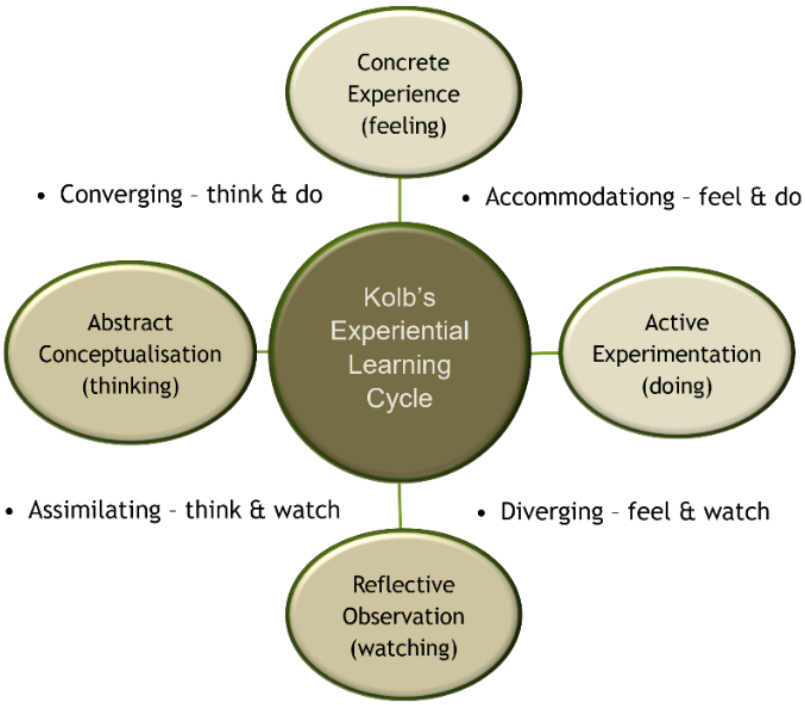


Figure 2.1. ***Kolb's Experiential Learning Cycle Diagram***. Adapted from Kolb's 'Learning Style Inventory' (McLeod, 2017b)

Different to Kolb's model is Fleming's VARK model, which is an adaptation of the older VAK model of perceptive learning categorised as Visual, Aural and Kinaesthetic. Fleming described kinaesthetic teaching as a means to help the student *"connect to reality, by means of experience, example, practice, or simulation"* (Fleming & Mills, 1992). He referred to kinaesthetic as a 'multimodal' approach because some, or all, of the perceptive modes of learning are inherent. In updating the model, Fleming subdivided the visual category from VAK into two separate perceptual modes, with 'V' referring to the visual "preference for graphical and symbolic ways of representing information" and introducing 'R' to refer to *"preferences for information printed as words*" (Fleming & Mills, 1992). This VARK model narrowed learning preferences into more defined categories and classified those who use two or more of these styles (apart from kinaesthetic) as multimodal. VARK became highly popular in academia as participant feedback from experimental learning studies gained prominence in education research (Clark & Mayer R, 2008). Typically, participants are presented with a VARK questionnaire to establish self-awareness of learning habits prior to a test. A follow up post-test questionnaire identifies the learning modality that participants perceived worked best for them (Slater, Lujan & DiCarlo, 2007; Bolliger & Supanakorn, 2011; Sankey et

al., 2011; Baskaran et al., 2015). The VARK questionnaire has been widely adopted by researchers as a tool to help educators match content delivery to a learner's identified 'style', in what is referred to as the 'matching hypothesis' (Cuevas, 2016), e.g., an auditory learner should have content delivered to them in an auditory format; a visual learner should have their content delivered to them in a more visual format. What appears to be widely ignored however, is that Fleming himself advises against such use:

> *"VARK is NOT intended to be used to enable teachers to "match" learning materials to the students' learning preferences. Nor is it intended to be used to identify those who are more likely to have better academic success"* (URL 2).

Despite this, the use of VARK by researchers persists for those very purposes, especially for undergraduate medical related disciplines. For example, a quick search of 'VARK learning styles 2021' in Google Scholar returns 'about 831' [sic] research articles published that year.

Many formulaic similarities appear across learning style models and thus, they are almost generic, with just slight deviations from each other. For example, Kolb's stages of 'Accommodating' and 'Converging' incorporate what could also be understood as the kinaesthetic element from VARK. This pattern has not gone unnoticed. Newton, Najabat-Lattif, Santiago & Salvi (2021) are critical of the abundance of learning styles that have been promoted in the absence of empirical data to test to their effectiveness for learning. This sentiment is mirrored by Sharp, Bowker and Byrne (2008) who point out the lack of validity or reliability of VAK as a tool stating that,

> *"Any evidence that VAK 'works', be it with instrumentation, activities or strategies, is, at the present time, entirely anecdotal" (p. 311).*

This reproach toward learning styles is summarised in the study '*The Learning Styles Educational Neuromyths'* which highlights a lack of studies employing scientific methods and problematic measurements in the area (Papadatou-Pastou, Gritzali & Barrable, 2018).

Out of the plethora of learning styles grew the movement of 'brain-based learning' models although connections to neuroscience were mainly terminological, relying on behavioural observations rather than any rigorous statistical evidence (Sharp et al., 2008). Terms like 'neuro-linguistic' came into existence to merge VAK and Howard Gardner's (1999) '*Theory of Multiple Intelligences*' into

programmes such as Alistair Smith's successful Accelerated Learning in the Primary School (ALPS) (Sharp et al., 2008). ALPS is attractive, offering strategies that teachers can employ to motivate students, foster self-esteem and create an anxiety free learning environment while prescribing positive feedback. As with many of the learning style models, progression through a cycle of steps is advised, the outcome of which is suggested to lead the student toward better understanding of their own learning preferences (Smith A, 1998).

ALPS has also been widely criticised in a similar vein to the misuse of learning styles. Smith refers to a significant amount of neuroscience as contributing toward the development of ALPS and so, it appears a robust programme for improving learning (Goswami, 2006; Dommett, Devonshire, Plateau, Westwell, & Greenfield, 2011; Mayer R, 2018). However, the neuroscience referenced as supporting ALPS has not proven the validity of the approach beyond Smith's own deductive reasoning. In later years, Smith acknowledged these shortcomings by stating that the references made to human intelligence and the brain were metaphorical and should not be seen as supporting or advising any particular approach to learning. He states that with hindsight, he *"would change the interpretation of brain research in this book to be less conclusive and more open to question"* (Sharp, 2008, p. 309).

An alternative perspective on learning styles is that educators have clearly found them beneficial in the classroom at some level, regardless of the lack of evidence. If this was not the case, then learning styles would not have been propagated or supported so widely in education circles. It is possible that the adoption of learning styles can motivate students to be more attentive in class. Motivation is in fact, a proven phenomenon for student engagement and academic success (Quillin & Thomas, 2015). This may have led educators to over-sell the value of learning styles beyond what the original researchers had envisaged (Sharp et al., 2008; Newton et al., 2021). More concerning, is the heavy marketing of learning neuromyths to educators as discussed in Goswami's review (2006), '*Neuroscience and education: from research to practice?*' These neuromyths include the concepts of tailoring lessons for the right or left hemispheres of the brain, timing learning with sensitive periods of synaptogenesis and even the claim that 'brain buttons' can be activated by pressing certain areas under the ribs to improve the visual systems' attention for reading and writing (Goswami, 2006). All are without foundation and

have led to dismissal of brain-based learning approaches that are unsupported by evidence:

> *"To the very best of our knowledge, independently verified quasi experimental and longitudinal studies producing conclusive evidence pointing unequivocally to such a close relationship between brain-based learning and children's academic performance do not exist" (Sharp et al., 2008, p. 308).*

The old idiomatic expression not to 'throw the baby out with the bathwater' applies here. A positive outcome of reports on learning styles is that there now exists an abundance of student feedback, identifying what students perceive to be helpful in terms of learning. This provides worthwhile insight into learner habits that may help educators to understand what motivates students in general to become more engaged in their learning. Once educators and students are disavowed of the misconceptions of matching educational material to suit a learner's identified preference, then adopting a learning style modality as an alternative form of classroom engagement rather than a prescriptive form may prove useful.

Overall, it is clear that learning styles should not be given weight beyond such use in the absence of empirical data. In this context, VARK remains a good feedback tool to help study participants become more self-aware of the tactics they employ during learning as well as potential alternatives. It also provides a shared language for use between researchers, educators and students when communicating different strategies that may add more creativity and engagement overall to lesson content and delivery (Brumpton & Kitchener, 2013). As advised by Gardner (2013), a better approach is to recognise that everyone has strengths and weaknesses for learning in different disciplines, as conveyed by his theory of multiple intelligences. He makes the point that true understanding can be demonstrated when knowledge can be disseminated in a variety of ways and in unfamiliar situations. Therefore, by presenting and examining learning material in different formats, the illusion of learning can be challenged more effectively.

Gardner viewed mental and physical activities as being related to having a bodily-kinaesthetic intelligence (Gardner, 1999) but unlike learning styles, does not view the intelligences as being disconnected; nor does he promote tailoring curriculum to suit any one specifically. He does, however, recognise the potential that technological advances have in extending more kinaesthetic engagement to include those with physical impairments (Gardner, 2013).

2.1.1 The use of digital technologies for visualising science

Digital technologies have assisted science learning to a great degree in providing multiple means of representation and engagement for the student. Much work has been done to highlight the pros and cons of presenting online education in a manner that reduces extraneous processing (unnecessary mental work) and for enhancing generative processing (motivation to learn) (Clark & Mayer R, 2008). For example, Mayer's 'Cognitive Load Theory' is based on evidence from cognitive research which shows that using single modality cues such as visual or aural content, are less effective when provided separately than when they are combined for semantic delivery (referred to as 'dual coding'). However, more physical and affordable engagement strategies for KL have not transitioned well to the online space and remain largely offline. This is especially true in relation to the molecular sciences, despite persistent recommendations from research to facilitate more online experiential learning environments (Gegner et al., 2009). Bree (2018) echos that advice:

> *"Design investigations with 'minds on as well as hands on'…Move away from the traditional, structured, memorisation themed instruction base to an experience learning base…Develop independence, responsibility, hands-on approaches and encourage independent thinking in students" (p. 43).*

Gamification and laboratory simulation packages are examples which utilise an online interactive KL approach and have gained ground as acceptable alternatives when students cannot physically attend undergraduate laboratories, as occurred during the recent Covid-19 pandemic, or when laboratory running costs are prohibitive (Bree, 2018). While the advantages of running virtual laboratories over physical ones may be advantageous from a time and cost point of view, Makransky, Terkildsen & Mayer R, (2019) found that when virtual learning became immersive virtual reality (VR), learning did not increase, despite increased presence. This outcome is somewhat surprising, as increased presence would suggest more attention and focus for the learning content in a manner that the student was essentially experiencing. This feeds into an ongoing debate amongst researchers as to whether media *"are mere vehicles that deliver instruction, and…do not influence student achievement, learning, or motivation"* (Makransky & Petersen, 2021) or whether it is the methods employed to study that influences learning success (Mayer R, 2003). Makransky's motivation stemmed from prior research which suggests a stronger

sense of presence correlates with a deeper understanding of learning material when a student's motivation to learn is increased through higher engagement, in this case, as with the use of VR. The cognitive theory of multimedia learning (CTML) (Mayer R, Hegarty, Mayer S & Campbell, 2005) suggests otherwise, in that immersion could be considered as adding extraneous details that distract from the lesson, thereby reducing learning and possibly causing cognitive overload (Mayer R, 2003).

In their 2019 study, the main objective for Makransky and colleagues was to evaluate whether there was any differential effect on learning if a science simulation was presented via low immersive, desktop media (PowerPoint on a PC) or high immersive, head-mounted media (VR). The topic for learning was mammalian transient protein expression, with a focus on laboratory techniques for cell culturing, transfection and protein expression. A secondary objective was to ascertain whether the method used to study would influence learning. This involved presenting the simulation with onscreen text, or with onscreen text and narration in both media formats. In addition, cognitive processing was measured during learning using an electroencephalogram (EEG).

The experiment adopted a 2 X 2 mixed design approach in which fifty-two students (30 females and 22 males) participated from a European university. The students were randomly assorted into two different study groups. The first group of 28 students received the science simulation which included the onscreen text (T condition) on both PC and VR. The second group of 24 students received the science simulation which included the onscreen text with narration (T + N condition) on both PC and VR. The students were tested individually and all followed the same protocol, regardless of whether they completed the simulation on VR first or on PC first:

a) Receive preparatory information.
b) Complete a participant questionnaire.
c) Student receives feedback.
d) Employ the interactive laboratory techniques for 15 mins (either VR first followed by PC or vice versa, depending on random assignment within groups).

Once a student had followed all steps to complete the first simulation, the same steps were repeated again to complete the second simulation. The participant

questionnaire was split into 3 sections A, B and C with each section containing 10 knowledge retention MCQs to test procedural and conceptual learning; and 10 transfer MCQs to test the student's ability to apply their new learning to novel situations. Students received section A prior to the first simulation, section B prior to the second simulation and section C, once the second simulation was complete. Therefore, the researchers could ascertain whether students knew any of the answers in advance of receiving the first simulation, as well as measure final learning once both simulations were complete.

In relation to the methods effect, no significant difference was detected between the text, versus text and narration conditions in contradiction to Mayer's redundancy principle, i.e., that learning is better when graphics are paired just with narration (N), versus when graphics are paired with both text and narration (T + N) (Clark & Mayer R, 2008; Liu, Meng & Roy-Campbell, 2022). It must be noted here that Mayer's study conditions were based on narration (N) versus narration with text (T+N), so the comparison is not quite equivalent. As for the media effect being tested, students were found to learn significantly more when a PC was used to deliver the lesson rather than VR. Overall, this indicates a media but not methods effect on learning which corresponds with some other research in this area (Mayer, 2003; Mayer et al., 2005; Sankey et al., 2011). Accordingly, this signifies that the development of a KL approach for use with molecular science topics need not be limited to the expensive and more advanced technological platforms such as VR. As demonstrated in Makransky's study, the more affordable and accessible PowerPoint software may provide an ideal platform for the development and application of online KL approaches.

EEG results from the study showed that students were approximately 48.8% more overstimulated during learning in the VR group. This may have led to reduced learning or possibly, the new sensory effect of this novel experience may have caused distraction. Hence, to achieve the best learning outcome, it is important that any KL approach developed would not emulate this overstimulation effect. One of the reasons Makransky posits as contributing to poorer learning using VR, is that the learning content itself was complex and was represented in a complex manner which, *"might have imposed a heavy intrinsic load on the participants as the sample in this study was made up of novices"* (Makransky et al., 2019, p. 11). If this were

true however, then the difficult content would have posed the same challenge to all participants, not just those in the VR group.

As with the Makransky study, the majority of science simulations are developed for lab practical knowledge, with a focus primarily on lab training to meet a skills outcome. They do not cover the background theoretical knowledge that scaffolds understanding. Significant lecture time is still required to bring students' learning up to a level that enables them to engage with simulations, or to make the connection between the lab work and theoretical aspects. Outside of laboratory work, the *'Anatomage Table'* (see Figure 2.2 as sourced with permission from Anatomage Inc., URL 3) is an example of experiential KL that has translated to a digital platform for teaching anatomy in medical disciplines.

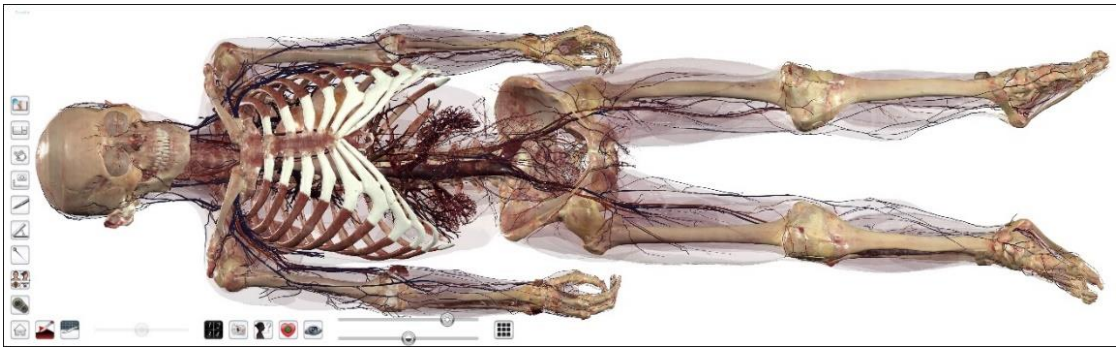
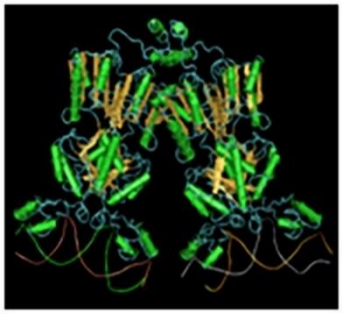


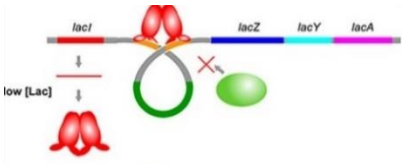
Figure 2.2 *Anatomage Table.* A 3D rendering of cadaver data. Photo courtesy of "Anatomage Inc. – Anatomage Table EDU."

A virtual life-sized cadaver lies on a table and users interact with it through touchscreen technology. The body can be turned to display a view through different layers, from skin to cardiovascular, giving users a realistically intimate and safe interaction that allows for self-paced learning of very complex content. However, it is specifically designed for anatomy related disciplines and does not yet cater for science learning at a molecular process level. As (Scanlan, Kennedy & McCarthy, 2021) note, developing online experiential techniques for use in learning anatomy are conceptually less challenging than developing online hands-on techniques for use in learning molecular science. Anatomy students will already be familiar with concepts (even from childhood) such as blood circulation, digestion, respiration and so forth; and with relatable terminology such as bones, blood cells, organs etc. In contrast, the molecular sciences are dense with abstract concepts, e.g., gene regulation, receptor activation, recombination, which are highly unrelatable to the

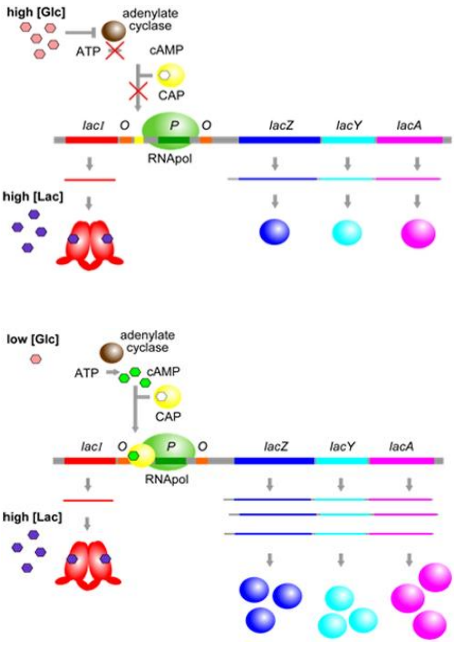
student's experience of physical reality. In addition, an extensive new science vocabulary must be learned which does not always provide an intuitive link to the abundant biochemical processes being learned. It becomes an obvious challenge to learning. To further illustrate the point, compare the Anatomage Table (Figure 2.2) with the illustrations outlining 'The Lac Operon Gene Regulation System' (Figure 2.3).



(a) The Lac I Repressor molecule blocks transcription of genes in the Lac Operon



(b) Negative regulation of the Lac Operon in the presence of glucose



(c) Positive regulation of the Lac Operon in the absence of glucose and presence of

Figure 2.3 The Lac Operon Gene Regulation System. a) (b) & (c) sourced online from 'The Lac Operon – Libre Texts' (*URL 4*).

The images in the latter are abstract explanations for the abstract concepts of the invisible! The Lac Operon illustrations serve to highlight how difficult it is to visualise, relate to and conceptualise the subject matter of biochemistry and similar molecular science disciplines. This presents an additional challenge toward designing an effective online KL approach for molecular science.

In his extensive review, Seel (2017) covers the theoretical approaches and research associated with learning through models. The type of models Seel refers to are not those discussed previously as learning procedures (e.g., Kolb's Experiential Learning Model). Instead, they are models that function to represent knowledge

about the world and phenomena in a simplified format and within a certain context, to aid understanding (Seel, 1991). Consequently, they are tools that can facilitate the ability to hypothesise, predict and address questions about the theoretical or to better communicate the known. Seel refers to multiple studies recommending the inclusion of models as tools for elucidating abstract topics from math and the sciences, with a special focus on simulation and visualisation using computer-based tools.

The process of generating such models requires the ability to visualise and to idealise, i.e., not all facts may be known or might be too complex to include for the purpose of creating a simplified representation to better understand something (Wimsatt, 1987). Seel gives an example of the Bohr model of the atom, which is closely similar to the quantum mechanics theory of the atom; although Bohr's idealised version is not fully correct, it is more easily understood and communicated than the latter. Models which can be conveyed using visual or tangible means are referred to as *explicit mental models*. In contrast, *implicit mental models* relate to the cognitive reasoning that goes on when mentally constructing a model (and which may be less easily expressed). According to Wu & Rau (2019), if students are constructing a model (whether implicit or explicit) and do not have access to an expert version for comparison, they risk thinking that their own conceptions/models are correct, even when flawed. Other studies have found that using models to learn can take longer, but the completion of learning tasks are more accurate as a result. 'Instance-based training,' for example, copying an image or tracing over an image, can lead to the opposite outcome in that learning tasks are faster to complete but less accurate (Domangne et al., 2004; Gillan et al., 2015).

Model building is a constructive approach and although better for learning, constructive approaches run the parallel risk of cognitive overload if too challenging (Chi & Wylie, 2014). However, when learners receive prior training for using a model-based approach, cognitive load does not increase and repeated task completion using the model can even become automatic (Seel, 2017). Therefore, it is possible that a constructive model of biomolecular processes could be well represented as a computer-based lesson on which to apply an online KL approach. Having explored the educational psychology research, an extensive review of neuroscience literature was undertaken to better scrutinise how we learn from the synaptic to systemic level and to judge how an online KL approach might be developed accordingly.

2.1.2 The neuroscience of learning

Up until recently, neuroscience had become comfortable with the notion that engrams, the neuronal pattern of memories, were largely influenced by the strength and frequency of neuronal activity which relies on the ability of cells to communicate across synapses. Many factors including environment, can influence gene and protein expression and activity within neurons that serve to modify synapses. Thus, neurons are changeable – they have plasticity (LeDoux, 2002; Squire, 2012; Costa, Martins, Tahiri & Duarte, 2022). The conception of engrams was challenged by researchers who transferred a long-term memory from one *Aplysia* snail to another (Bédécarrats et al., 2018). A selection of *Aplysia* snails underwent sensitisation conditioning over a period of time, receiving a tail shock to initiate a siphon-withdrawal reflex (SWR). Shortly after this period, the RNA from sensory neurons was injected into snails who had not undergone conditioning and on subsequent stimulation, the unconditioned snails displayed the same SWR. Amazingly, a long-term memory had been transferred.

Although the *Aplysia* snail has a very simple nervous system in comparison to humans, the Bédécarrats study draws attention to our limited understanding around the influence of molecular dynamics involved in memory and the behavioural mechanisms associated with learning. It also points to a fundamental realisation, as eloquently stated by LeDoux (2002):

> *"Most systems in the brain can learn from experience, which means that the transmission properties of their synapses can be altered by experience. In this sense, learning itself is not the specific function that circuits were built (by evolution) to perform. Learning is instead a capacity of synapses, something that contributes to the way circuits work" (p. 86).*

LeDoux (2002) outlines various studies from the early 20th century which elucidate the neural mechanisms of learning and memory. In the 1930s, Hamburger and Levi-Montalcini (O'Leary, 1992; Oppenheim, 1998) were able to demonstrate how nerve growth and selection during early brain development relies on three principal occurrences: exuberance, use and subtraction. During this period, many more synapses are made than are needed – growth is exuberant. However, synapses that are not used eventually regress and take on the appearance of having been pruned back.

Further evidence for regression was provided by Rakic and colleagues (Rakic et al., 1986) followed by Hubel and Wiesel in the 1960's who explored and proved

the ‘use’ tenet of selectionism (LeDoux, 2002). The latter duo conducted experiments on cats in which they closed one eye early in development. Injecting a tracer into the thalamus, they demonstrated how the pre-synaptic axons in the visual cortex regressed when they did not receive a visual stimulus. However, the neurons that did receive a visual stimulus from the open eye, sprouted more connections than was normal per axon. Results were different when adult cats were experimented on in the same way. No detrimental defects were detected suggesting that the cortex can re-organise connections in early development, but not in later life. Therefore, synapses increase in complexity and can create new connections in direct correlation to how active they are. Understanding this may explain why education psychologists have found that active learning approaches lead to better learning outcomes than passive approaches.

In 1949, Hebb proposed a mechanism for learning based on how synapses undergo modification which facilitates the plasticity of neurons. Although originally proposed to explain learning and memory, his concept or ‘Hebb’s rule’, agrees with the selectionist view of how synapses are formed. Hebb’s rule is often referred to in layman’s terms as ‘*cells that fire together, wire together’*. In other words, if two neurons are firing action potentials (AP) at the same time and one is synapsing with the other, the strength of their firing, hence connection, increases. This results in homeostatic changes (Kukushkin, Tabassum & Carew, 2022), that lead to cell modifications including metabolic, that serve to strengthen and stabilise the existence of such synaptic connections, enabling more efficient communication. This process of strengthening synaptic connections also offers an explanation for why the integration of learning modalities as per the dual coding theory, has shown validity in cognitive testing (Xie, Mayer, Wang & Zhou, 2019).

Delving deeper into the molecular mechanisms of early synaptic development, other influential factors include neurotransmitters and their synaptic receptors. Glutamate is possibly the most important neuro-transmitter in the nervous system (Kolb & Wishaw, 1996; Squire, 2012) with an intrinsic role in the generation of long-term potentiation (LTP) at NMDA receptors within the Hippocampus - an important process for creating memories and for learning (Watkins & Jane, 2006; Zacharopoulos, Sella, Cohen Kadosh K, Hartwright, Emir, Cohen Kadosh R, 2021). Hypofunction of NMDA receptors can impair memory and normal cognitive development (Newcomer et al., 2000; Watkins & Jane, 2006). Post-synaptic NMDA

receptors are vital for neurons when connecting as these receptors can match the output firing and input firing pattern of neurons. They can both record which presynaptic terminal was active (from where the glutamate was released), as well as the activity of the postsynaptic cell itself (LeDoux, 2002; Hayashi, 2022). In effect, this allows the post-synaptic cell to retain communication with the most active neurons in its environs, ignoring those that are less active, hence weakening those connections. This may explain why more active study strategies lead to better learning engagement as discussed earlier.

Neurotrophins are another essential molecule aiding the growth and survival of neurons. They are released from the postsynaptic cell when an AP occurs and diffuse backwards across the synaptic space for uptake into presynaptic terminals (LeDoux, 2002; Costa et al., 2022). This prompts the development of axon sprouts from the terminal, allowing for new connections to be made. As only the active presynaptic neurons receive neurotrophins, only those neurons will be able to generate new growth. The end point of an inactive neuron is axon retraction and programmed cell death. However, if that cell can be given a dose of neurotrophins, it can be rescued. The availability of neurotrophins is limited so neurons must compete with each other for survival. The more active the neuron, the more likely it is to survive. In this way, the nervous system is wired to respond to nature and nurture events (Kolb & Whishaw, 1996; McLeod, 2017a). It is generally accepted that the complex network of connections in the human brain matures just before puberty. Therefore, with learning later in life, new synaptic connections are not forming but are being added to or enhanced (LeDoux, 2002). The groundwork has been done in early development and again, neuronal activity is the driving force behind these adjustments.

These neuroscience studies demonstrate that many parts of the neural system are capable of learning and for that to occur, it must be capable of forming different neural memories (Kolb & Whishaw, 1996; Bédécarrats et al., 2018). Certain neurons may be more ‘plastic’ than others depending on location and these areas can be further subdivided for memory. For example, the visual system can retain memory for colour, shape and motion (Kolb & Whishaw, 1996) all of which are processed in parallel in over 30 different regions of the brain (Greenfield, 2003). When combined correctly, this synchronous firing of neurons across widespread parts of the brain is believed by some to temporarily bind neurons together into a

pattern that can become represented in working memory, although there is less evidence for that than there is for the role synchronous firing plays in facilitating synaptic plasticity (LeDoux, 2002). According to Leisman, Moustafa & Shafir (2016):

> *"The importance of plasticity as the chief mechanism for the promotion of learning, verbal, and procedural memory, and motor behavior cannot be understated. Neuroplasticity underlies the actual number as well as the strength of connections between neurons as well as connectivities between brain regions" (p. 11).*

Therefore, divergent signals from the peripheral and central nervous system travel into the various brain regions along sensory axons, to create a convergent output response from the motor cortex (Greenfield, 2003). Greenfield explains:
"As your neuronal connections grow, shaped by your particular experiences, so the dialogue between your brain and the outside world becomes more two-way" (p. 152). The consensus is clear from neuroscience – learning cannot occur without experience and our experiences are shaped by our learning.

2.1.3 Learning through movement

Young children are often referred to as being 'like sponges' when it comes to learning and this can be attributed to the exuberance of neuronal connections from infancy throughout early childhood years (Leisman et al., 2016). Piaget, the cognitive theorist of early childhood development, observed toddlers and young children in the exploration of their environment and recognised the common thread for several developmental milestones (Wellington, 2000; McLeod, 2018) that could be relied upon to reasonably predict a child's cognitive growth, or lack thereof. Observation was possible due to a child's ability to physically interact with their environment and others, in order to construct new knowledge as well as to develop a self-awareness of their role within it, showing the direct relationship between experience and learning.

Early childhood years are characterised by an immature cognitive awareness that develops alongside uncoordinated, clumsy motor behaviour (Leisman et al., 2016) and "*reduced postural activity in childhood*" (p. 1) can be linked with the onset of developmental delays. Disruption to communication between the frontal lobe (responsible for executive processing) and motor regions of the nervous system can lead to:

> *"Impulse control disorders, both inhibitive and facilitative, as well as disorders of executive function and judgment, either inhibited or facilitated, and judgment disorders can all be attributed to dysfunction of this network and its control of motor and non-motor cognitive behavior" (Leisman et al., 2016, p. 2).*

These cognitive-motor interactions, the authors state, are the same required for problem solving. The integration of physical and cognitive brain areas makes sense from an evolutionary standpoint as it enables adaptation various environments (Leisman et al., 2016). Accordingly, the more sophisticated that movements became, the more advanced the cognitive processes became too (LeDoux, 2002; Greenfield, 2003).

In other words, movement and action are integral to learning and our ability to communicate. Excluding disorders of the nervous system, movements require governance, attention, intention and co-ordination from learned cognitive processes (LeDoux, 2002; Greenfield, 2003; Leisman et al., 2016). The cerebellum is key to integrating and coordinating patterns of movement (Hazeltine & Ivry, 2002) which initially require conscious attentive and repetitive practice to form a declarative or 'explicit' memory. Through familiarisation, less attention is required and patterns of movement become stored as unconscious, non-declarative or 'implicit' memories which enable the automatic retrieval of sequenced actions (Hazeltine & Ivry, 2002; Kandel et al., 2014; Camina & Güell, 2017) as can be witnessed in the fluid playing of a piano or the thoughtless changing of gears in a car. Explicit memory requires more active processing to generate internal cues for the recall of factual information, such as for people, places and events and provides the "spatial and temporal context of specific experiences" (Camina & Güell, 2017). Thus, an online KL approach should ideally facilitate an element of repeated practice to support the generation of internal cues (Hazeltine & Ivry, 2002; Halpern & Hakel, 2003; Roediger & Karpicke, 2006).

While the processing and recall of explicit memories depends greatly on the hippocampus and corresponding cortices, implicit memories rely mainly on cortical regions associated with the fine control of movement (the striatum, aka., basal ganglia) and emotion (amygdala) (Kandel et al., 2014). Implicit memory is a more passive process encoding for what is perceived, often with little attention for later recall (Kolb & Whishaw, 1996; McLeod, 2010) but priming can improve that recall (Xie et al., 2019). For example, in education, separating material into manageable

related subcategories or 'chunking,' can prime retrieval during learning as it is easier to recall a smaller volume of material at a time than large. This practice enables better consolidation of the material into an overall mental model (Kogl, Camfield, Mcfall & Land, 2016). Thus, recall can be hugely affected by the way information is presented and subsequently processed (Kolb & Whishaw, 1996; Mayer R, 2003; Fiorella et al., 2017; Fiorella & Mayer R, 2018). Perhaps this explains the variable techniques of KL, from assembly to role-play, which serve to prime learning through repetition and experience.

2.1.4 Recall, technology and the brain

The peripheral findings relating to digital media such as temptation to distraction and transactive memory cannot be ignored if a KL approach is to be successful in an online format. Distraction is a common theme associated with computer use and online digital media in general. Temptation to distraction is quite startling when the effects on learning outcomes are considered and may be representative of the distraction symptomatic of computer use in the home (Chesley, 2005; Wilson, Reinhard, Westgate, Gilbert, Ellerbeck, Hahn, Brown…Shaked, 2014), school (McCoy, 2016) and workplace (Mark, Iqbal, Czerwinski & Johns, 2014). The study "*Just Think: The challenges of the disengaged mind*" examined 'default-mode processing*,'* or thought that is directed inward (Wilson et al., 2014). The authors explored whether people deliberately disengage from their surroundings to spend time thinking and whether that thinking process was pleasurable. Their survey found that 95% of Americans chose to pass time by reading, watching television, or socialising, in preference to simply "*relaxing or thinking*." Results from the Wilson study correlate with other studies which indicate distraction is attractive to avoid boredom (Mayer R, 2003; Mark et al., 2014). Thus, any online KL approach developed should aim to mitigate distraction rather than add to it and as such, would need to strike the right balance for engagement.

A concern for translating a KL approach to an online platform is the observation that digital technology may interfere with the memory process that supports active learning (Firth, J., Torous, Stubbs, Firth, J. A., Steiner, Smith . . . Sarris, 2019). Worries that deeper knowledge is lost to memory by using online search engines to seek information instead of reading from say, an Encyclopaedia, are backed by evidence (Carr, 2011; Sparrow, Liu & Wegner, 2011). Sparrow's

study is particularly interesting in that relatively simple but convincing experiments were designed to explore whether easy access to an online source can reduce recall abilities, thereby reducing the memory encoding required for learning. Participants were presented with 40 general trivia statements to read on a computer and made aware they would have to recall that information later. However, half the participants were led to believe that the computer would erase the information after reading, whilst the other half believed the information would be saved. Participants typed up all statements to better focus their attention and as an additional aid to the recall process. In addition, half the participants from within each group were encouraged to actively remember as much of the information as possible. Once reading and typing were complete, all participants were asked to write down as many of the statements as they could recall.

Results revealed that those in the 'erase' group fared significantly better than those who still believed the information was available to them on computer, regardless of whether they had been told explicitly to remember or not. Hence, it can be concluded that knowing information was readily available to access from an online external source led to a reduction in learning, as the same effort to remember simply was not made in comparison to that of the 'erase' group. This phenomenon is known as '*transactive memory'* and is a management strategy to use mental resources more efficiently. Transactive memory can also occur without the use of technology in situations such as team building exercises, where knowledge is held collectively by the group – the external source in this instance – rather than at a deeper individual level (Bell et al., 2015). Without the support of a team for collective recall of newly acquired knowledge, it can be reasoned that technology poses a risk to learning anything. Therefore, requiring the learner to problem solve through an online KL approach that incorporates an active repeat recall of lesson content should reduce the likelihood of transactive memory and increase episodic memory. In addition, a KL approach that can provide a sufficient interactive challenge is more likely to reduce the temptation to go web browsing for solutions and instead, keep them engaged in committing the lesson to memory.

Ergo, memory formation is more complicated than originally believed and research is still delving into its mechanisms for learning. Kolb & Whishaw (1996) describe memory development as analogous to a river flowing through different areas - the function of neuronal activity is like the river and the various brain

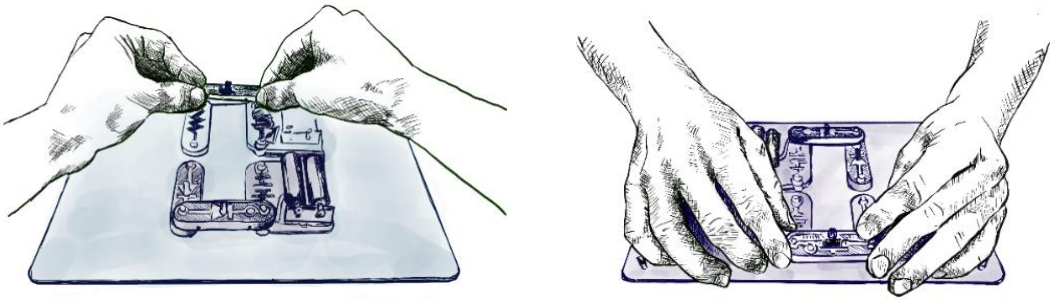
structures it flows through are the memories being developed; they flow rather than remaining housed in any one particular area of the brain. Memory, thus learning, can be modified through synaptic activity and result in the strengthening or weakening of certain aspects of that learning or memory. Something is 'learned' when those synaptic networks can correctly feed-back what was inputted. Of course as with other structures in the brain, the cerebellum does not function without extensive innervations to other regions of the brain, in particular with the basal ganglia which also governs motor control (Hazeltine & Ivry, 2002). Thus, movement, learning and memory, i.e., the core of KL, are highly interdependent. Knowing this makes the relatively recent research on mirror neurons all the more exciting.

2.1.5 Understanding mirror neurons and motor imagery for KL

Mirror neurons are not yet fully understood but are hypothesised to function in interpreting and understanding the actions of others (Leisman et al., 2016; Camina & Güell, 2017). This enables us to replicate or 'mirror' those actions and behaviours we observe. According to Leisman et al., (2016) this:

> *"Internal simulation of motor acts during imagery or observation of others' movements enable social cognition, empathy, and understanding of others' intentions and emotions, as well as affect one's own emotions. But beyond the cognitive–motor interaction at the brain level, movement itself can affect cognition" (p. 10).*

A study demonstrating this effect was conducted by Fiorella et al., (2017) in which students viewed an online video showing the assembly of a circuit board from two different perspectives. This involved viewing the hands of the same person performing a task in both first and third-person perspective (see Figure 2.4). When the assembly is watched from the first-person perspective, the brain of the viewer interprets the hands in the video as their own, thereby increasing learning. Knowing this leads one to speculate whether a KL approach that is based on an onscreen interaction, might also lend itself to a version based more on observation for those with a physical impairment which limits onscreen interaction? If such an online KL model could be conceived, then complementary interaction/observation versions of the same approach would provide a more equitable tool for learning amongst students in a class.



(a) First-person perspective *(b) Third-person perspective*

Figure 2.4 *Perspective Effect*. Illustrations adapted from 'It's All a Matter of Perspective: Viewing First-Person Video Modeling examples Promotes Learning of an Assembly Task' (Fiorella et al., 2017)

The perspective effect was found to be especially suited for complex tasks. Hence, Fiorella recommends extending the perspective effect:

> *"to teaching topics in STEM domains, such as in the use of physical and virtual models to teach complex spatial relations of molecules in chemistry, or in the use of concrete manipulatives" (Fiorella et al., 2017, p. 663).*

Neuroimaging research shows that the brain applies context to certain stimuli and experiences through,

> *"the participation of the specific sensory, motor and emotional modality in understanding language and, on the other hand, the existence of large regions of the brain (the inferior parietal lobe and a large part of the temporal lobe) involved in tasks related to understanding" (Camina & Güell, 2017, p. 3).*

In connecting motor language to motor movements, an EEG study conducted by Pulvermüller, Härle and Hummel (2001), demonstrated how action verbs relating to various body parts elicited the strongest neural response in accordance with the expected somatotopic organisation of the cortex. Somatotopy refers to the topological organisation of the primary motor cortex and how it is linked for intercommunication between specific regions of the body (somatic) and for the

control of specific bodily movements in those regions. In neuroanatomy, the motor homunculus (see Figure 2.5) is a graphical representation of this intercommunication between the somatosensory system (bodily perception) of the peripheral nervous system (PNS) and the primary motor cortex of the central nervous system (CNS) (Crossman & Neary, 2015; Nguyen & Duong, 2023). Verbs were chosen as they are "*the primary tool for talking about actions"* (p. 145). For example, 'to walk' activated the topographically related region in the motor strip associated with movement of the leg; 'to talk' activated the correspondingly related effectors near the Sylvian fissure. Similarly, motor imagery has been found to activate regions of the motor cortex linked with execution of related motions in what appears to be the brains way of generating internal simulations for the learning of actions *"in a comparable fashion to that observed with an actual performed movement"* (Leisman et al., 2016, p. 3).

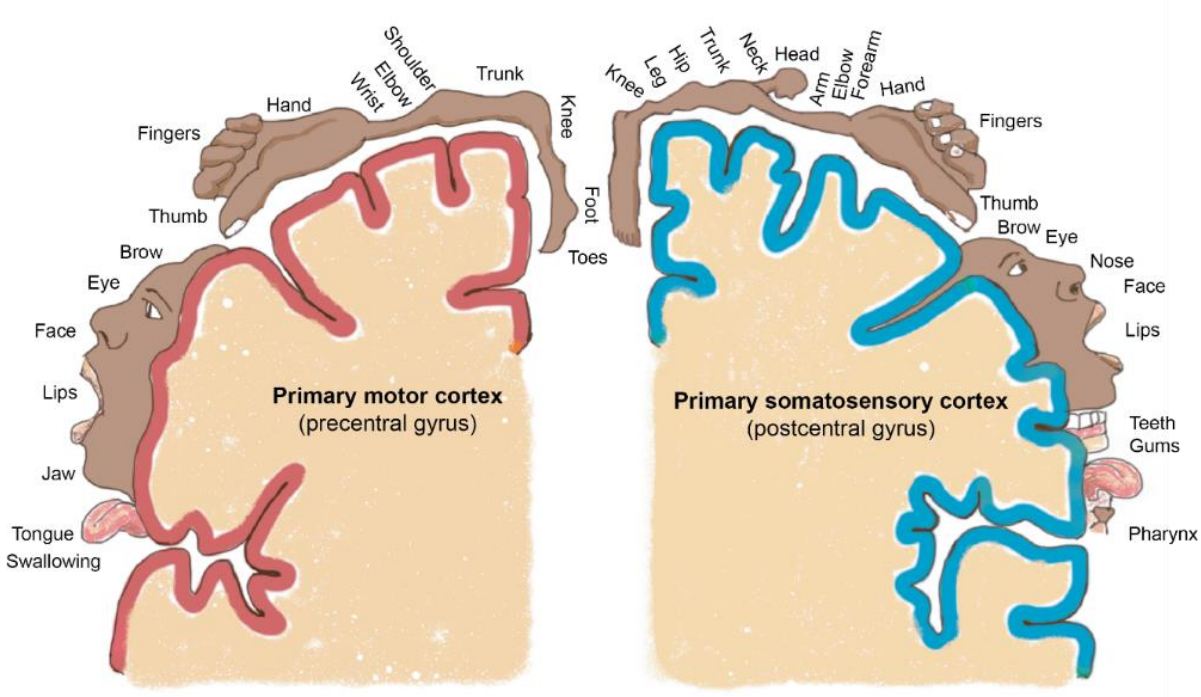


Figure 2.5 ***Motor Homunculus.*** Illustration adapted from 'Homunculus of Primary Somatosensory Cortex in Blue,' sourced from (URL 5). The homunculus is an illustrative representation of how body parts might appear in size if compared directly to the number of motor cortex neurons associated with their control. As can be seen in the illustration, body parts that require precision movements and fine co-ordination such as the tongue, face and fingers, are proportionally larger than body parts requiring less precise movements.

The authors expand on this with an example of tetraplegic patients who were,

> *"able to operate an EEG-based control of a hand orthotic with nearly 100% classification accuracy by mental imagination of specific motor commands"* (p. 3).

This is of particular interest when considering the feasibility of using graphics to facilitate an online interactive KL approach. Thus, whether actions are imagined or carried out, they have,

> *"the same functional relationship" in the brain and "the kinesthetic mental image of a motion configuration is accompanied by the same innervation pattern found in the motion itself"* (Leisman et al., 2016, p. 3).

2.1.6 Appraisal of e-learning strategies for KL science lesson content

There are several factors to consider before applying KL to molecular science, as informed by e-learning research.

***Science content itself should not be a confounding factor*:** Lesson content needs to be well structured to facilitate coherent navigation for the learner. Text and graphics should be well constructed to avoid becoming a barrier to learning.

Present a challenge: The educator should generate content that will challenge the learner to think more deeply and so, be able to synthesize new concepts into a concrete whole for deeper understanding.

Motivation to engage in learning*:* For the learner, cognitive engagement is linked to motivation and the willingness to take the necessary steps required to learn. Through their study, '*The ICAP Framework: Linking Cognitive Engagement to Active Learning Outcomes'* Chi & Wylie (2014) established that student learning increases sequentially as their engagement progresses from *"passive to active to constructive to interactive"* (p. 219).

Recall can be supported by priming*:* In a meta-analysis of 150 studies, Schneider et al., (2018) investigated the effects on learning when cues for recall or 'signals' were added. These signals served to highlight pertinent points within a lesson. Colour cues elicited a strong positive effect, whilst text cues proved to be stronger than pictorial cues. The only domain to return a non-significant result for signalling was the *"maths/statistics"* (Schneider et al., 2018, p. 17) category, which the authors suggest is due to the abstract nature of mathematics. Hence, it is questionable whether signalling would be effective if applied to abstract concepts in molecular science. One solution may be to create digital illustrations of molecules and augment them with relevant text cues to incorporate the positive effects of signalling into an online KL approach. However, embellishing any learning content

with signals should be done with intention for the purpose of priming or guiding learning, rather than for the sake of making the lesson more aesthetically pleasing.

Stick to the point: Mayer R, (2003) explored the effects of adding interesting but non-essential information to multimedia learning content with what are termed, 'seductive details', a temptation of sorts to lose focus on the relevant material. Students who did not receive the additional seductive details were able to generate 90% and 34% more 'creative answers' in both book-based and computer-based conditions respectively, than those who had received the additional information. Mayer called this ability to learn more deeply without distraction from extraneous detail the *coherence effect.* Further effects found to be applicable to learning outcomes, regardless of whether material was presented in paper or computer-based format, are outlined in Table 2.2 (adapted from Scanlan et al., 2021). These validated multimedia learning effects are highly relevant for e-learning strategies for KL science and align with the *cognitive theory of multimedia learning* (CTML) as described by Clark and Mayer R, (2008).

Table 2.2 Established E-learning Guidelines for the Development of Online Lessons

Guidelines	Source
Coherence effect: Exclude extraneous details and keep content specific	(Mayer, 2003)
Personalisation effect: Use conversational language rather than formal	(Mayer, 2003)
Multimedia effect: Present lessons in a multimedia format	(Mayer, 2003; Sankey, Birch, Gardiner, 2011)
Spatial contiguity effect: Position relevant text alongside informative pictures	(Clark & Mayer, 2008)
Segmenting Principle: Design navigational controls and facilitate paced learning	(Clark & Mayer, 2008)
Deliver audio with diagrams or animation but not with both text and diagrams	(Clark & Mayer, 2008)
Facilitate interactions with online learning content & test using difficult concepts	(Gegner, Mackay, Mayer, 2009; Saadé, Morin, Thomas, 2012)
Perspective principle: View online lessons from 1st person perspective	(Fiorella, van Gog, Hoogerheide & Mayer, 2017)
Provide dual cues for recall, e.g., visual with auditory	(Xie, Mayer, Wang, Zhou, 2019)

The CTML model focuses on the use of multimedia in lessons, for example, pairing words (printed or spoken) with graphics, and posits the idea (as with neuroscience) that working memory is limited, so attention must be paid to material if it is to be processed for storage in long-term memory. The CTML model reflects several principles outlined below from cognitive psychology research. It refers to 'channels' for incoming stimuli in what is a simplification of the neuroscience, but which is helpful toward understanding aspects of how material can be presented and processed internally into mental images or 'schema' (Kandel et al., 2014). The four principles are as follows (Clark & Mayer R, 2008):

1) We have separate '*dual channels'* for handling visual and auditory content.
2) Our processing capabilities have '*limited capacity'* and are restricted to integrating information in small portions at a time through each of the channels.
3) When we attend to relevant information, organise and assemble it coherently and then integrate it with our prior knowledge, we engage in '*active processing.'*
4) Our ability to subsequently '*transfer*' knowledge from long-term learning into a new hypothetical situation is an indication that learning has occurred.

Clark and Mayer proceed to outline how these four principles in turn rely on three key demands of our cognitive capabilities and they are extraneous processing, essential processing and generative processing.

- ***Extraneous:*** relates to the unnecessary mental pressure added by having to attend to irrelevant information presented in learning content.
- ***Essential:*** refers to the level of mental effort required to assimilate content from a lesson - the more complex the representation of the content, the more mental work required (as found by Makransky et al., 2021 cf).
- ***Generative:*** grows from the motivation that drives the direction of mental effort toward making sense of learning material in order to gain a deeper understanding.

In addition, Clark & Mayer found that where studies reported significance for both computer and paper-based learning, effect size for learning tended to be larger in many instances when lessons were delivered via computer. However, contradictions also exist to this general finding. In a further study proposing the *static media hypothesis* Mayer R, Hegarty, Mayer S and Campbell (2005) conducted experiments

comparing paper-based learning with text and illustrations versus computerised animations with audio description. Results showed that fixed media such as the written word, diagrams or illustrations, lead to better learning gains than dynamic media content (animations or narration). The researchers concluded that content delivered via static media is easier to process mentally as more time can be spent focusing on the key subject matter as opposed to dynamic media which may cause cognitive overload, leading to poorer learning outcomes.

Mayer R acknowledged that other research does not support his static media hypothesis (Tversky, Morrison & Betrancourt, 2002) and discussed general problems with the methodological approach and poor control in experiments involving animations as contributing factors. He further recommends that e-learning studies include the ability to pace dynamic media for online learning; provide the same learning advantages afforded by static media; and allow participants engage in active discussion of content during learning to promote active processing. A KL approach designed for online application would need to be mindful of these recommendations.

2.1.7 Review Discussion

The main premise that has emerged from reviewing the literature is that there is a lack of knowledge transfer between the disciplines of neuroscience and education psychology in relation to KL. Better knowledge integration and collaboration between these two disciplines stands to benefit the development of suitable online kinaesthetic approaches for engaging with more abstract learning material, as found in the molecular sciences.

Developing an approach that can directly engage the student with the learning content is more likely to reduce distraction and improve focus on the topic being learned. The less boring or negative a lesson is perceived to be, the more time the learner may spend on learning. KL lends itself well to this purpose as it is not limited to any single modality or technique and can be applied creatively to learning, e.g., role play, assembly, etc. There also remains scope for an online learning approach that can better capture the benefits of the signalling effect and to encompass the more abstract learning domains such as molecular science.
As outlined in the introduction, KL is an experiential modality that is significantly underdeveloped for online learning in comparison to more traditional approaches such as verbal dissemination, reading, writing, and graphics, all of which are all

well-developed for dynamic representation of material in the online learning space. The employment of kinaesthetic approaches toward learning advanced molecular life science is likely to enhance the learning of such science. While kinaesthetic techniques are routinely adopted in the physical world for learning tangible topics online as with the Anatomage Table, it is less clear how to apply an online kinaesthetic approach to intangible and invisible science content. Hence, it remains a conceptual and practical challenge. Consequently, significant research and development will be necessary to bring effective kinaesthetic formats to online learning for molecular science in a scalable and affordable manner.

Although outside the scope of this review, the more recent understanding for the role of mirror neurons and motor imagery in learning is highly significant. That is, whether actions are imagined or practiced, they have "the same functional relationship" in the brain and:

> *"the kinesthetic mental image of a motion configuration is accompanied by the same innervation pattern found in the motion itself" (Leisman et al., 2016, p. 3).*

For the purpose of learning science, this fact indicates huge potential for developing online visuals that support a KL approach, without the need to be highly immersive as with VR and similar disruptive technologies.

2.2 Thesis Proposal

In reviewing the literature, a gap was identified for (a) defining a cross-disciplinary understanding of KL, (b) developing online KL approaches and in particular, (c) for application of online KL to the molecular sciences. This led to the analysis of KL from two main perspectives – the psychological and the neuroscientific. In doing so, what constitutes as KL has been clarified to a greater extent than has been achieved previously, as 'kinaesthetic' is typically considered in isolation to a particular discipline. In particular, this review suggests that by utilising the advantages of digital technologies, scientists and education psychologists can enhance how complex molecular science topics are taught, learned and assessed. This thesis aims to provide empirical data to determine whether an online KL approach is indeed feasible and applicable to advanced molecular science topics.

CHAPTER 3

RATIONALE FOR KL LESSON DEVELOPMENT, DESIGN AND USE

3.1 Introduction

The main objectives of this research were to identify, design and investigate novel approaches and tools for facilitating kinaesthetic learning of molecular biology content online. To meet this challenge, a variety of online lessons incorporating a kinaesthetic approach to teaching and learning were developed to aid the understanding of advanced science concepts and for enhancing long-term knowledge retention. This collection of innovative, online kinaesthetic techniques and lessons are referred to as a '*kinaesthetic learning system'* (KLS). Over the course of this research, several online kinaesthetic approaches and interactive tools were developed and tested in learners. Through an iterative approach, the successful online KL lessons were isolated from those deemed to be unsuccessful, according to a set of standards which are outlined in section 3.3.1 '*Evaluation criteria for developing the KLS framework.*' Key parameters governing the research design were that the approaches and tools developed must be scalable, affordable and amenable to widespread sharing and adoption for use by other educators.

3.1.1 Motivation to develop a kinaesthetic approach in an online format

Researchers across disciplines from science to education psychology, are advocating a change to learning and assessment approaches which can be applied with continuity, from second level through to third level education (Smyth, Banks & Calvert, 2011; Girvan et al., 2016). More recently, there has been a particular focus on problems arising from the use of standardised high-stakes testing in academia which are well documented internationally (O'Brien, 2008; Shute et al., 2016). Some emerging evidence suggests the recent Covid-19 pandemic has further magnified inadequacies in education delivery and assessment, with higher negative consequences for those already on the margins (Gamage & Perera, 2021), although the long-term positive or negative impact of switching rapidly to online learning is still uncertain (Curtin, 2020; Kumar et al., 2021; Van Beusekom, 2022). Online education continues to evolve in tandem with advances in digital technology and

presents opportunities for enhancing science learning and assessment as never before.

In the review '*Advances in the Science of Assessment*,' Shute et al., (2016) explores the potential for enhancing learning and assessment through technologically rich environments (TREs) that can better measure the whole learning experience, while also advocating for the *"reconceptualization of current assessment`s with innovative assessments that capitalise on technological advances" (p. 34).* TREs can expand on traditional, static means of learning and assessment by enabling videos, animations, dynamic text, and diagrams (2D to 3D) to be weaved into lesson content and thus, turn learning into "a dynamic occasion approximating the vividness of learning in vivo as if the student were "really there" solving the task" (Shute et al., 2016, p. 37). However, as Mayer R., et al., (2005) discovered in developing his *static media hypothesis*, there remains ambiguity in terms of learning for the assertion that computers trump static media, as discussed in Chapter 2. This is not unexpected given the recently new emergence of TREs and the ongoing exploration of their capacity for, and application to, education. Teachers are time poor when it comes to developing or researching pedagogical approaches suitable for translating to TREs and rely on the reports that emerge from education research (Sharp et al., 2008). TREs are expected to create a more authentic learning environment which inspires greater attention and interest by enabling learners "to experience nonlinear methods of exploring information," as well as facilitating the measurement of "the cognitive, emotional and kinaesthetic processes educators wish to probe in their learners" (Shute et al., 2016, p. 38).

In terms of developing an online kinaesthetic learning approach, TREs hold strong potential for assessing higher order cognitive skills (HOCS) (Co, 2019) through the engagement of complex problem solving which supports both soft and technical skills development, including the ability to: hypothesise outcomes and understand consequences; discriminate the relevant and reliable information from research; plan/revise/modify strategies; test ideas and receive timely feedback; collaborate with others and coordinate courses of action; be able to synthesise information coming from multiple diverse streams and thus, develop the cognitive flexibility to become a creative, innovative and cooperative graduate (Shute et al., 2016). Gardner (2013) also foresaw the potential for innovative technological application to improve kinaesthetic engagement for those who are physically

impaired. Thus, molecular science stands to gain from TREs which can help to make theoretical, intangible content more visually and kinaesthetically accessible. To better understand the concerns around high-stakes assessments and to determine how a KL approach might serve to reduce reliance on such a model, a further review was undertaken. This helped to inform how a KL approach might be applied to best effect for realistic, long-term use in academic learning and assessment for the molecular sciences.

3.2 An overview of the high-stakes assessment model and need for a KL approach

3.2.1 The Irish context

Traditionally, assessment methods in second level (high-school) education have been used in a standardised format to measure student learning through mass recall and understanding, culminating in a terminal high-stakes examination (Shute et al., 2016; Smyth et al., 2011). In an Irish context, secondary school students (typically aged 12-15 yrs) have three years of learning across approximately nine examinable subjects (and excluding non-examinable) condensed for measurement in a once-off sitting of the *Junior Cycle (JC)* state exam at the end of 3rd year. Different schools will have slightly alternative subject offerings (e.g., Spanish), but the examinable JC subjects are fairly homogenous nationwide to include: (i) Irish, (ii) English, (iii) French or German, (iv) maths, (v) history, (vi) science, (vii) home-economics or geography, (viii) music or art, (ix) woodwork or technical graphics or mechanical drawing or construction. Subjects requiring practical kinaesthetic skills such as music, woodwork, art, etc., include a hybrid assessment element, with project work contributing toward the final mark but the learning experience is nonetheless intensely focused on the final examination of the ~9 subjects (O'Brien, 2008). Excluded from that list but still a requirement in the class timetable are non-examinable subjects such as, (x) physical education (P.E.), (xi) religion, (xii) social personal and health education (SPHE), (xii) civic social political education (CSPE), and (xiv) computers.

Students are channelled into taking subjects at either an 'ordinary' or 'higher' level for senior cycle, depending on their JC performance. This has consequences

for the final state exam, the *Leaving Certificate (LC)* taken 2-3 years later, as grades at higher-level are awarded more points than corresponding grades at ordinary level. For example, a grade of 90-100% (H1) at higher level is awarded 100 points whereas the equivalent percentage at ordinary level (01) is awarded 56 points. A grade of 60-69.99% (H4) is awarded 66 points, while the equivalent percentage at an (O4) grade receives 28 points. A bonus of 25 points is awarded for taking higher level maths. Students must meet a threshold of points for entry into a third level course in an Irish institution and for science disciplines, that threshold typically exceeds 500 points (the maximum that can be achieved is 625, incl. bonus math points).

Hence, the Irish learning experience remains intensely focused on the mass recall of learning material at just two main timepoints, the JC and LC exams (O'Brien, 2008). In addition, the typical weekly timetable of an Irish Leaving Certificate secondary student comprises ~9 subjects, even though the majority of third level institutions in Ireland require points based on performance in six subjects to meet course entry requirements. Of all the subjects, math and science are considered to have the most challenging content due to the abstract nature of concepts and theoretical subject matter. This is reflected in the perpetual call for more uptake in science, technology, engineering and math (STEM) subjects at both second and third level, especially for females and to fill a knowledge gap in industry. A 2019 report, '*What Now For STEM – Accenture in Ireland,*' disclosed that 69% of teachers felt STEM subjects were too hard for pupils to learn and took up too much teaching time (44%). Students agreed (56%), with almost a third attributing this to how the subjects were taught. Higher stress levels were consistently reported amongst exam year students in Ireland across studies from the 1980's-1990's, especially amongst females.

3.2.2 The international context

The large-scale model of standardised high-stakes testing emerged following the development and use of SATs in North America from the 1960s onward. Some criticism internationally, is that this model of assessment provides only a superficial measurement of learning from which a student's actual academic ability cannot truly be predicted (Shute et al., 2016). Reports from U.S. studies found that student perceptions of high-stakes testing were equally negative, with expressions of boredom, withdrawal, anger and anxiety as contributing factors. Others stated being

judged on a single test was unfair (Smyth et al., 2011), while Kennedy (2006) points out that:

> *"giving only a grade to a student does not provide adequate feedback on his/her performance since the grade simply indicates an overall level of competency" (p. 68).*

Smyth relates similar perceptions amongst English students who preferred the assessment of coursework over exams, but still found pressure and stress associated with both formats. Thus, it could be argued that standardisation in this context fails to support curriculum in fostering a genuine ability for various subjects. Nor is it reflective of the affective state and motivation of students, or of the coaching element geared toward exam performance over learning (O'Brien, 2008; Smyth et al., 2011). Therefore, although the ongoing use of large-scale standardised tests have led to stricter design methods that are checked rigorously for psychometric robustness, little room is left for the input of feedback or the accommodation of a more holistic learning approach (Minarechová, 2012). This, Shute argues, *"has systematically dwarfed classroom assessments"* which have instead become *"tools for preparing students to perform on the large-scale tests that really matter"* (Shute et al., 2016, p. 36).

The OECD (Looney, 2009) believes it is possible to improve high-stakes assessments by revisiting how standardisation is applied to testing (e.g., using standards to measure problem-solving and communication skills instead of content learned); by developing a wider range of measures for students and schools; and by continuing to measure the impact of such an assessment approach on learning and teaching. Consequently, different countries have begun using different formats of high stakes exams and different strategies to implement them. For example, in Portugal, school evaluations are both internal and external, with emphasis on the need to develop more innovative teaching approaches for inclusion and equality.

In post-communist countries where the high-stakes model has only recently been adopted, a mix of national and international tests are used such as the National Test in Romania at 8th grade (equivalent of Irish JC), which makes up 75% of a student's summative mark, with the remaining 25% accounting for annual averages from 5th grade (Minerachová, 2012; Glavin, 2017). In the Czech Republic, students at grades 5 and 9 receive high-stakes exams while in Slovakia, Monitor 9 exams are used for 9th graders. Recent reforms to make high-stakes assessments more

innovative in Slovakia include greater school autonomy and different exit examinations from secondary school. The latter includes a 'matura' examination at the end of secondary school which does not rely primarily on producing written content but instead tests knowledge orally of mathematics, a foreign language and two other optional subjects of choice. The language and literature of Slovakia is tested in both oral and written formats. For students who do not intend to go on to university, 2-3 year vocational programmes are offered to enable students graduate secondary school with an apprenticeship certificate. Final examination of the apprenticeship involves oral and practical elements (Looney, 2009). Other countries like Sweden, have reduced the pressure of relying on high-stakes assessments for entry into third level by increasing the routes for entry through university aptitude tests, work experience and even, allowing an applicant to make a case for admission.

In addition to national tests, many countries use international tests such as Trends in International Mathematics and Science Study (TIMSS), Progress in International Reading Literacy Study (PIRLS) and the Programme for International Student Assessment (PISA) (Minerachová, 2012). The PISA test, conducted by the OECD, is issued every three years to over 6,000 secondary school students (aged 15 yrs 3 months to 16 yrs 2 months) across approximately 85 countries, to test their reading literacy, science and math skills. Students undergo a 2-hr test which draws on knowledge and problem-solving abilities, not memorisation of facts (URL 6). Countries are ranked by student performance in the test and as of the latest results in 2018, China and Singapore top the list, with Ireland in 9th place and the U.K. in 10th position. As mirrored by the pressure of high-stakes exams, this ranking causes pressure for countries that fair less well (e.g., the United States is currently in 22nd place) as economic success appears to correlate with PISA ranking. Hence, there are U.S. critics who try to blame the lower performance on having a disproportionate number of disadvantaged students, but the OECD have shown this to be a fallacy (Looney, 2009). In contrast, there is scepticism over the results returned by China as the distribution of the PISA tests was limited to just 4 specifically chosen provinces. This behaviour reflects the pressure of school reputation and student competition that occurs with high-stakes exams for students and which trickles down to policy and academic practice levels. Evidence for this lies in the fact that since the introduction of high-stakes testing, national test scores have increased year on year, which researchers have linked to "familiarity with test-taking" rather than an improvement

in teaching and learning (Harlen, n.d.; Linn, 2000), with 80% of teachers in one national U.S. survey confirming they paid greater attention to teaching toward testing (Madaus & Russell, 2010). Furthermore, Harlen (n.d.) discusses financial implications giving the example that in the U.S., prior to the introduction of the SAT, 80% of the budget for schools in 1967 went to standard education. By the end of 1990, this had reduced to 50%.

It is now widely acknowledged that a single exam cannot encompass or measure all of a student's learning accurately (Looney, 2009; UNESCO, 2020). While some countries which are new users of the high-stakes model have already made adaptations to its implementation as discussed, other countries which were long-standing users of the model have dropped its use altogether (e.g., Wales in 2004) (Minarechová, 2012). Those relying on the high-stakes model had their curriculum particularly affected by the closure of schools during Covid-19, resulting in postponement of exams or outright cancellation in some cases (GEMR, 2020), such as cancellation of the JC in Ireland. All things considered, formative assessments are viewed by many as a more equitable tool for shaping and measuring learning and to either replace or mitigate the negatives of high-stakes summative assessments (Looney, 2009; UNESCO, 2020). The following sub-sections consider the impact of the high-stakes assessment model in more detail and explores alternative assessment formats to structure an effective online kinaesthetic learning and assessment approach.

3.2.3 Factors perpetuating the use of high-stakes exams

State exams and the subsequent consequences for students, schools and even a country's economic interest can be substantial (Hill, Corbett & St. Rose, 2010; Smyth et al., 2011). For example, in North America assessments from the 1990s were used to incentivise successful exam performance by means of cash bonuses to schools, funding or conversely, sanctions at an individual level (e.g., students not allowed to graduate). This can turn into sanctions at community level through negative school ranking (Smyth et al., 2011; Shute et al., 2016) or the practice of streaming (O'Brien, 2008). In Ireland, the LC points system exacerbates and reinforces the inequity of high stakes examination as all stakeholders are acutely aware of the 'points race,' (Walshe, 2021; Kennedy, J., 2022) which receives substantial media coverage annually. LC points can influence subject choice rather

than interest in the subject itself, based on the perception that points are more difficult to attain with certain subjects, including science.

Hence, what should be an accurate means of communicating an individual's academic ability has been treated at times as a tool of inequality, to be wielded by policy makers or those with a vested interested in controlling access to training, employment or further education (O'Brien, 2008). This statement is not far-fetched. In a longitudinal study, Smyth et al. (2011) review much research highlighting how higher grades are particularly associated with *"the élite professions, a smoother transition to employment, and greater access to white-collar jobs" (p. 6).* This is supported further afield by research which attributes the perpetuation of inequalities in social class, race and gender to standardisation (Minarechová, 2012; Tawfik, Reeves & Stich, 2016; Shute et al., 2016).

To replace dependence on the high-stakes assessment model, Smyth proposes that education should reflect in full, the range of knowledge and skills developed by the student, by adopting a wider selection of assessment modes (Smyth et al., 2011). This can be achieved, the authors say, by providing continuity in learning expectations as students' progress to higher academic tiers, reducing the amount of detail in subject content and shifting the focus toward developing key skills such as critical thinking.

3.2.4 Student perceptions affect academic performance

A striking report from research is that students from the lower and working classes perceive further education at university to be a risky choice due to costs, social, and psychological factors, whereas middle-class students believe they have 'more to lose' by not continuing to third level education (Smyth et al., 2011). Empirical research concurs (Bloom, 2007). At second level, this attitude is fostered greatly through the school ethos and environment, parental and teacher feedback and student-peer relationships (O'Brien, 2008; Minarechová, 2012). In Ireland, the nature of a teacher-student relationship was found to have a strong impact on the outcome of LC grades. For example, a positive interaction from 1st year to 3rd year (JC level) did not have any significant bearing on LC grades in 6th year, while a good relationship in 5th and 6th year was linked to better LC grades. However, a strong correlation was found between negative relations and a negative outcome for LC

grades, even if that negative relationship was only experienced in the earlier years (1st - 3rd) of secondary school (Smyth et al., 2011).

Interestingly, Smyth found that by 6th year, students who held a positive academic self-image and with aspirations to continue to third level, had come to view 'good teaching' as a teacher who taught for the LC test, and were impatient with those teachers who sought to provide learning experiences beyond exam related content. Thus, in-class dynamics between a teacher and their students is a highly relevant consideration for research and curriculum design (Minarechová, 2012). This is not a new phenomenon, with Jamieson and Thomas (1974) outlining in the '70's how teachers held an almost coercive power within the classroom, with students having a role that was more akin to the institutionalised powerlessness of "inmates." Although obvious improvements have come about since, students of today report similar sentiments to their student forebears in feeling powerless over a learning experience that weighs so heavily on their futures.

The pace of instruction is another element known to have a significant association with grades achieved and if a teacher-student relationship is poor, this problem is unlikely to be overcome. Pressure to meet what teachers predict may 'come up' in terminal exams such as the LC, further exacerbates the pace at which material is covered as well as increasing stress amongst students (Smyth et al., 2011). This represents an unintended consequence of the large-scale standardised assessment model, in that it now influences *"what knowledge is taught, the form in which it is taught, and how it is taught," (p. 6).* Learning has become focused on skills for test-taking over deeper understanding for content, or for the higher order cognitive skills that might be gained from learning that falls outside the exam remit (O'Brien, 2008). Content can be passed over too quickly in the effort to cover all bases rather than to engender true learning of the subject matter. The outcome is rote learning, cramming, and the private purchase of extra-curricular tutorials to cover material in more depth; to recover learning where the classroom dynamic is poor; or where staff absenteeism has been an issue.

Therefore, while large-scale standardisation enables comparability amongst students and schools nationally, the inequalities, consequences and stress (Smyth et al., 2011; Shute et al., 2016) arising from this assessment model may nullify the original purpose of measuring knowledge acquired. This highlights the need for a formative learning and assessment model that can rely on objective measures of a

student's academic ability. Ideally, such a model would provide a means of learning outside the classroom for more individual, self-paced and self-directed study. Maintaining the anonymity of the student if using as a formative assessment would support more neutral feedback.

3.2.5 Assessing online learning

In terms of assessments, Mayer provides a strong model for judging the depth of understanding gained from a learning task. His use of dual assessment by knowledge retention and transfer testing (Mayer R., et al., 2005) have become a popular standard for many studies measuring the effectiveness of online or 'e-learning.' The knowledge retention test is designed to assess procedural knowledge and concept development. A good example of the dual assessment format applied to science content is found in Makransky et al., (2017). In his study, Makransky used 10 multiple choice biology questions (MCQs) to measure recall from a laboratory simulation of a university level science lesson on mammalian transient protein expression.

Questions were generated by experts, including two psychologists, a psychometrician and the two scientists from Labster responsible for developing the 4 virtual simulations used in the study. In the paper, an example of a knowledge retention question is given as:

> *"How should you use your OptiPro medium for complex formation when both DNA and Expifactermin CHO reagent is diluted? A) Heated to room temperature; B) Headed to 56°C; C) Heated to 37°C; D) Cold, taken from storage at 4°C)" (p. 5).*

Similarly, the transfer test was also based on 10 MCQs that were situational and required more problem solving based on the newly acquired knowledge of the participant. The example from the paper is as follows:

> *"A delivery company is delivering frozen cells to you, but you have a meeting with your boss at the time of delivery. What is your best chance to ensure the cell's survival? A) Ask your boss to wait 20min. Thaw the cells and put them in liquid nitrogen; B) Ask the delivery company to leave the cells at room temperature. This is the best temperature for thawing frozen cells, and they can be stored later; C) Ask the delivery company to put them in a water bath at 37°C that you've prepared. The cells can survive until you are back; D) Ask the delivery company to put them in a water bath at 56°C that you've prepared. This is the optimal temperature for thawing frozen cells)" (p. 5).*

Transfer testing as defined by Clark and Mayer R (2008) *"relies on retrieval of new knowledge and skills from long-term memory during performance"* and are useful in showing that participants must have a deeper understanding of what has been learnt in order to problem solve in a new situation. However, the scientific understanding of 'long-term' as it relates to long-term potentiation of neurons (LeDoux, 2002; Watkins & Jane, 2006; Squire, 2012) and the formation of engrams as discussed in Chapter 2, is different to what might be interpreted by a non-scientific reader as memory that is stored for retrieval after a long period of time. Many of Mayer's studies which used transfer testing as well as the above examples from the Makransky study, were given to test participants immediately following experiments. Thus, they are indicative of episodic and semantic long-term memory (Kandel et al., 2014), which is memory that lasts for more than ~30 seconds (Cherry, 2022), and not necessarily the ability to recall after a period of time, say days, weeks or months. For learning to occur, procedural memory developed through the repetition of executive and motor skills is important, although simple repetition of a task does not guarantee the acquisition of a new skill (O'Reilly, Symons & MacLatchy-Gaudet, 1998; Camina & Güell, 2017). If this is true, a KL and assessment model which affords a challenge to cognition combined with an element of practice, is likely to be successful. More recently, neuroscience has elucidated the role of spatial cognition in non-spatial learning processes such as verbal reasoning for STEM topics (Cortes, Peterson, Kraemer, Kolvoord, Uttal, Dinh, . . . Green, 2022). This further suggests that a model which can be presented in a highly graphical format may enhance learning for science, moreso than relying on the mainly text-based format of science material which currently predominates.

To test the level of understanding and depth of detail retained from any learning including e-learning, the subject matter should be returned to at a later date (De Jong, 2010; Korbach et al., 2016). This approach is taken in traditional education settings, with exams at the end of a semester that test detailed learning from material covered over several months. The problem as previously discussed, is when learning over several years is examined in bulk as a high-stakes assessment in a single sitting, as per the Junior and Leaving Cert exams in Ireland. For researchers, a better approach for realistic testing is to combine post-test recall and transfer tests across two or more timepoints. This would better reflect whether a particular experimental technique is truly measuring long-term learning retention.

3.2.6 Aligning evidence-based learning approaches to a kinaesthetic learning and assessment model

Educational research faces more challenges in attempting to measure learning objectively in human participants, compared to more quantifiable subjects such as for example, colonies in a petri dish (oversimplification acknowledged) or the number of times a rat runs an arm in a maze. With studies involving humans, there will always be a level of random variability that reduces the strength of any reported sample statistic as a measure of the relevant population (Price, Jhangiani, Chiang, Leighton & Cuttler, 2022). In addition, the phenomenon known as the 'Hawthorne Effect,' suggests that student awareness of being tested in experimental conditions may affect their performance differently than it would in normal learning and examination conditions (Wellington, 2000; Sankey et al., 2011). For this reason, it is recommended not to overlook the practical significance of an outcome, *z* whether that outcome includes statistical significance or not. The Hawthorne Effect can be mitigated by using a placebo curriculum or control.

3.3 Methods for Designing the KL Lessons

3.3.1 Evaluation criteria for developing the KLS framework

Education internationally has shifted toward a more student-centric teaching and learning approach (Kennedy, D., 2006). This can be partly attributed to the Bologna Agreement (1999), which brought more clarity to qualification structures and for how qualifications are described, through the introduction of learning outcomes.

> *"Learning outcomes are statements of what a student is expected to know, understand and/or be able to demonstrate after completion of a process of learning." (ECTS User's Guide as cited in Kennedy, D., 2006)*

Bloom's Taxonomy (1956) if often consulted to help structure learning outcomes as it provides an extensive list of 'active' verbs, which Bloom used to help classify lower to higher order cognitive processes in a hierarchical fashion (see Figure 3.1). Aside from the six levels which fall under the 'Cognitive' domain, Bloom also categorised learning for the 'Affective' or attitudinal/behavioural domain and the 'Psychomotor' domain, involving neural and muscular co-ordination when learning.

Kinaesthetic learning approaches could be seen as falling into the latter domain but in reality, there is a certain amount of overlap across all three domains for learning.

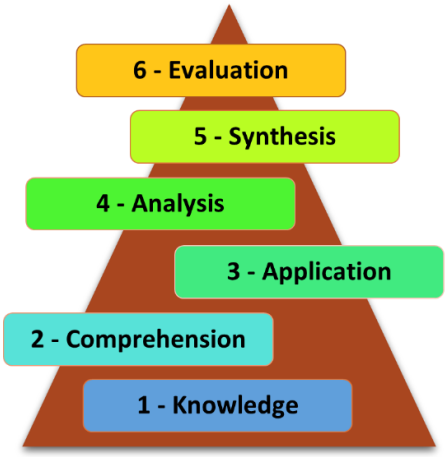


Figure 3.1 Bloom's Taxonomy. Lower levels of learning begin at the bottom tier of 'Knowledge' with higher learning achieved at the level of 'Evaluate' in the top tier. Educators are encouraged to design lessons that can scaffold progression up to the highest tiers of Bloom's Taxonomy.

It was important for this study to develop a model that would have practical significance and which could be tested empirically for statistical significance. This ensured the focus remained on creating challenging but kinaesthetically engaging science content with ecological and content validity (Cohen, Manion & Morrison, 2007; Price et al., 2022; Shabatura, 2022). The lesson layout and tasks aimed to reach the highest tiers of Bloom's Taxonomy (first developed in 1956) in terms of content, task and challenge to the learner, thus promoting the generation/use of HOCS. Methods for evaluating the KLS were considered and those outlined in Table 3.1 were deemed highly relevant.

Table 3.1 Evaluating the KLS

Methods for Evaluating the KLS
1. All items must comply with ethical approval and be amenable to the application of scientific research methodology, i.e., design, build, test, repeat.
2. Be possible to assess for comprehension, recall and long-term retention of learning.
3. Simple lesson and assessment design format that lends itself to reproduction in accessible platforms, e.g., Microsoft Office, Google Forms.
4. Affordable, expandable, scalable, user friendly and lead to intuitive understanding.

5. High engagement to maintain interest and attention.
6. Construct validity – online kinaesthetic approaches must be a true translation of offline.
7. Face validity - be capable of providing an honest measurement for learning
   Criterion validity – assessments must measure the approaches accurately.
8. Must build on expertise and knowledge.

Several ideas for a KL approach applicable to science were conceived and analysed initially as follows:

KLS 1 Assembly and Controlled Disassembly – kinaesthetic approach based on model building and the practice of assembling and disassembling a whole for creative imagining of multiple outcomes. To be used with science content by disassembling and reassembling diagrams from a selection of pre-disassembled diagrams.

KLS 2 1st Person Perspective – use of a visual of a hand to draw components of a science topic (the lac operon onscreen via a video-scribe) to mimic the kinaesthetic act of drawing from a first-person perspective, thus activating mirror neurons for learning (Fiorella et al., 2017)

KLS 3 Personal Choice Interaction – students have freedom to use onscreen colouring tools to colour or shade various components within the lesson or add their own comments towards aiding them memorise the lesson, imitating tactile active participation.

KLS 4 Story boarding – students will be given what appears like a comic strip of a biochemistry event onscreen, e.g., DNA transcription. They must then choose a 'character' from that strip, e.g., RNA polymerase, and create a story board from their character's point of view. This combines tactile elements of kinaesthetic role-play and has high creative and concept formation value.

KLS 5 Trial and Error – students must join text within boxes to appropriate diagrams of a conceptually difficult topic, e.g., the lac operon CAP-cAMP binding mechanism for activation of transcription. These boxes and diagrams will rearrange themselves automatically onscreen and the student will have to repeat the process.

KLS 6 Personal Pacing – allows the student choice over whether or not to animate segments of a lesson, or to keep them static as in paper-based format. They will also be allowed control over the pace of that lesson and will be able to revisit or replay lesson segments of their choice. This addresses an important advantage that paper-based learning has over computer learning for self-pacing (Mayer et al., 2005).

KLS 7 Diagram formats – learners will be presented with a variety of diagrams, each depicting the same lesson content but differing in terms of complexity, colour palette, formality etc. Learners will be able to freely interact with and move components about. Results should reveal whether any one particular diagram format is superior to others in terms of promoting learning and engagement. This supports the multimodal aspect of kinaesthetic learning.

Given the time required to analyse, evaluate, screen and subsequently develop a KL approach, it was only possible to proceed with one main theme for the purpose of thoroughly testing within the timescale of the thesis. From the above ideas, KLS 4 Story boarding appears to reach the highest level of hierarchy in terms of Bloom's Taxonomy as it requires the student to evaluate concepts to creatively imagine themselves as a character, describing their metabolic role through the 'eyes' of that character. This idea did not progress for testing as there was a possibility that student performance might have too many variables to assess accurately, e.g., developing in-depth narrative for just one specific molecule rather than a holistic understanding for the whole. The other ideas required technical expertise beyond the scope or time of the research team to develop and this also moved away from a key criterion to produce a simple, affordable KL approach with easily accessible resources. The theme of assembly was evaluated as being highly controllable, readily producible with little expense as it was diagram based, modifiable directly by the educator and student, and agile for repurposing across different lesson topics. Hence, the kinaesthetic assembly approach was accepted for progression.

3.3.2 Testing the KLS for realistic application in science learning

It is questionable whether testing in realistic situations is truly being achieved in current education research as the standard material for learning typically involves a short text piece of <500 words, containing relatively familiar concepts with familiar language, e.g., lightning formation, (Mayer et al., 2005), bicycle pump (Bobek & Tversky, 2016), sea otters (Karpicke & Blunt, 2011), word or picture lists (Roediger & Karpicke, 2006) or relatively familiar biology (O'Day & Karpicke, 2021). In contrast, undergraduate level molecular life science requires significantly longer text to explain a concept and typically, several concepts are linked together for a lesson. In addition, students need to develop scientific literacy to understand and assimilate the lesson (Carrillo-de-la-Pena, Baillès, Caseras, Martínez, Ortet &

Pérez, 2009). Thus, it could be argued that science education is not served well by studies which do not use comparable subject material to measure learning.

To ensure the content validity of online KL lessons and to test in a realistic setting for better evidence of practice, a decision was made early to use science material on universally relevant molecular science topics for delivery and completion in typical education settings, rather than in an experimental environment. As the above review of research has shown, more continuity in learning expectations across different knowledge tiers is required. Hence, a plan was formulated to develop a framework that could guide lesson development and assessment within the same platform, but which would be applicable for use across multiple knowledge tiers, from second level through to undergraduate and postgraduate.

Software for implementation of the KLS was explored extensively to begin generating an inexpensive and user-friendly TRE and included Xara Graphic Design; Inkscape; Microsoft Office Word and PowerPoint; Adobe acrobat, illustrator and Photoshop (see Table 3.2). PowerPoint was chosen as the most appropriate platform as it is a popular, user-friendly, highly shareable application internationally in academia at many levels and the main presentation format used in UCC lectures. All students and staff in UCC have free access to PowerPoint and are expected to be competent in its use. In addition, it has the capacity be used as a desktop application independent of internet access once initially downloaded. Thus, ecological validity was also supported.

As discussed in Chapter 2, strong correlation exists between prior achievement in a subject and subsequent performance in exams, which can be further complicated at second level by the nature of the student-teacher relationship and pace of learning. To mitigate some of these factors and maximise the advantages of online learning, it was important to develop a KL lesson that facilitates self-paced, self-directed learning and which could provide continuity of format from second to third level. This would enable the student to revisit the KL lesson repeatedly and self-test their understanding by including challenges and tasks for exploration.

Table 3.2 Software Considered for Implementation of the KLS

Software	Pros	Cons
Xara Graphic Designer	Intuitive tools and graphics easy to illustrate and interact with. Can be used independently of internet access as desktop app.	Subscription/user; not suitable for research purposes where study participation is transient. Not conventional in education. Layout may confuse. Difficult to adapt.
Inkscape	Free vector graphic software with intuitive tools for illustration.	More suitable for developing logos and graphics but not for long text content. Not conventional in education. Internet access required. Layout may confuse. Difficult to adapt.
Adobe Acrobat	Conventional and affordable use in education (organisation subscription for staff and students). Suitable for graphics and long lesson text. Easy to share via email. Can be used independently of internet access as desktop app.	Kinaesthetic interaction with graphics not possible. Layout continuous & requires page scrolling. Difficult to adapt.
Adobe Illustrator	Excellent for illustrating graphics and for text formatting. Interaction with onscreen content possible. Can be used independently of internet access as desktop app.	Subscription/user. More suitable for creating graphics but not for long text content. Challenging platform to learn. Not conventional in education. Difficult file type to share. Difficult to adapt.
Adobe Photoshop	Excellent for manipulating images with some interaction possible if set up by the educator. Can be used independently of internet access as desktop app.	Subscription / user. Kinaesthetic interaction very limited and requires technical expertise. Combining long text and images difficult. Challenging platform to learn. Not conventional in education. Difficult file type to share. Difficult to adapt.
Microsoft Word	Conventional and affordable use in education. Suitable for inserting graphics and long lesson text. Easy file type to share and easy to adapt. Can be used independently of internet access as desktop app.	Kinaesthetic interaction possible but awkward/glitchy. Layout continuous & requires page scrolling.
Microsoft PowerPoint	Conventional and affordable use in education. Suitable for inserting or creating graphics and long lesson text. Easy file type to share and easy to adapt. Kinaesthetic interaction possible and easy to use. Rapid navigation through page clicking; can segment lesson sections. Can be used independently of internet access as desktop app.	File types can become large depending on the number of slides and graphics and can become slow to download or share.
Online webpage	Conventional and relatively affordable for researchers to set-up. Excellent for hosting large content and interaction may be possible. Easy to share and possible to segment sections.	Webpage cannot be adapted by others. Technical expertise required to create the webpage, content and any interaction. Internet access required & potential ethical concerns for safeguarding participants data.

The generic slide-by-slide structure of PowerPoint was ideal as it allows for rapid movement back and forth through a large amount of material via a click, rather than a scrolling or page turning mechanism. This presented the opportunity to create lesson slides which could each be followed by task slides. In theory, the student could interact with the task and return to the previous lesson slide to assess their knowledge against the 'expert' version (Wu & Rau, 2019) – independently of the educator, outside of the classroom and without having to generate new material. The educator could also escalate the challenge level of tasks to encourage further learning, without the need to rewrite the lesson itself. Both student and educator would have the option to save multiple iterations of a lesson, as well as the option to work live collaboratively or asynchronously in class with others. Such an adaptable format also promotes the critical thinking and creativity that can otherwise be lost when learning and assessments are over-focused on exam performance as already discussed.

The pool of students available for the undergraduate study were mainly from the schools of science or medicine and would therefore have a proven aptitude for science. This was overcome by choosing an especially advanced topic that students were unlikely to have prior exposure to. The Lac Operon gene regulation system in the bacterium *Escherichia coli* is usually introduced in 1st- 2nd year medicine or 2nd-3rd year science. This topic, which covers positive and negative gene regulation, builds on the foundational language and fundamental concepts that scaffold learning in the early months or first year of study.

To ensure that any learning could be correctly attributed to a kinaesthetic assembly approach, other variables that might independently support learning such as the use of mnemonics, were avoided. For the same reason, any factors which might negatively affect learning and be incorrectly attributed to a kinaesthetic assembly approach were reduced as much as possible, such as confounding grammar. Consequently, attention to the language of the lesson was critical. Text for the lesson was adapted directly from lecture notes and typed into PowerPoint. The aim for the written language was to have it so well structured, that reader confusion or frustration would not set in before having to try out any online kinaesthetic interaction. To maximise understanding and minimise confounding factors such as ambiguous terms, the connection between concepts was clarified for the learner. For example, the original wording of one sentence was "*The enzyme*

Beta-Galactosidase splits lactose in two." This explanation is rather vague as it requires the reader to make the connection between lactose and its products glucose and galactose. The wording "splits in two" also implies two equal parts are produced, which is not the case. A more accurate way to describe the process is to use unambiguous, technical wording as follows: "*The enzyme Beta-Galactosidase splits lactose into glucose and galactose."*

The Lac Operon lesson is a conceptually difficult third level science lesson and becomes even more so if introduced to a non-science or early science target audience. To identify just how many new concepts are in the Lac Operon lesson (from a non-science background point of view), a separate sentence or short paragraph was created for every new concept introduced. This yielded over 40 short paragraphs, indicating there are at least over 40 new concepts alone in this Lac Operon lesson. The significance of being able to quantify concept content and establish a system of standard references for rating and comparing lesson complexity became apparent very quickly. For instance, readily relatable concepts are commonly used as lesson content in Mayer's studies into learning as discussed at the start of this section. There is also a high likelihood that Mayer's study participants would have been well acquainted with the vocabulary of the lessons, e.g., pumps, brakes, lightning and so forth.

In contrast, the KLS study participants would not have the science vocabulary to explain the new ideas being introduced. Therefore, the concepts were extremely abstract and extra challenging – it effectively involved teaching completely new ideas with a set of unfamiliar words. This required careful reflection owing to the number of new and advanced concepts and led to the development of a *Concept Table* (see Table 3.3) which could be used to rate the difficulty and depth of a lesson (any lesson) in terms of a hierarchy of concepts. Basic concepts as identified in the paragraphs of the Lac Operon lesson were entered in a manner similar to bullet points, to roughly capture the number of concepts under four main categories, i.e., science concept, new language/vocabulary, descriptive analogy, and information related content which could be expanded upon if desired. Points were assigned for the number of new concepts introduced, new language terms, descriptive analogies and information items.

Table 3.3 Concept Table for the KLS Lac Operon lesson

Concept Total: 40	
4	DNA in all living things **:** inherited : instructs : proteins
2	Cell functions : amino acids make proteins
3	DNA segmented into genes : genes encode proteins : bacteria have genes
7	Copies genes : proteins made from template : free movement : need to bind at certain points : signalling : specificity - of binding & of transcribing : response
8	Promoter attracts RNA polymerase : linked to genes : strong and weak promoters : sugar break down : lactose genes : help for promoter : proteins can bind together : formation of CAP-cAMP complex
3	Protein binds to DNA : signals RNA pol on binding : protein dormancy and activation
2	cAMP can activate by attachment : proteins have enhanced function as a complex
2	Special sites for different molecules : complex grabs and directs RNA pol
2	Enzyme catalysis : nutrient break down
4	Proteins that can sense nutrients : physical repression : lactose interaction & physical removal : freedom for genes
3	Acetylation : new functions : physical removal
New Language Total: 24	
2	DNA, proteins
2	Worker molecules : amino acid building blocks
2	Genes : E. coli
3	RNA polymerase : transcribed : expressed
5	Promoter : Lac genes : CAP : cAMP : CAP-cAMP complex
2	Operon : Lac Z, Lac Y and Lac A genes
1	Catabolite Activating Protein (CAP)
1	Cyclic Adenosine Monophosphate (cAMP)
1	CAP-cAMP activating site
2	Enzymes : Beta-galactosidase
1	Lac repressor
2	Acetylation : allolactose : acetyl group
Descriptive Analogy Total: 8	
1	DNA instruction manual
2	Proteins as worker molecules : amino acid building blocks
2	Photocopy : train
1	Complex 'grabbing' RNA polymerase
2	Lac repressor 'sitting' and physically preventing RNA polymerase
Information Total: 11	
1	Bacterial division

3	Role of proteins : abundance : size range
2	Number of genes : most commonly studied bacteria
1	Explanation of term ‘read’ for lesson
1	Bacterial study to understand human gene regulation
3	Speed of lactose break down : importance of enzymes : study of enzymes in bacteria

Since science is built on factual knowledge, it should be possible to break information into simpler lesson formats or build them up into more complex offerings. However, this can be difficult to achieve when working with advanced molecular science content. In this regard, it was envisaged that the concept table might act as a tool toward scaling science content up or down in complexity in an objective, structured and measurable way. Lesson difficulty and depth could be rated by a hierarchy of concepts, alongside other variables. For example, the concept table presented here identifies 40 key concepts within the undergraduate level Lac Operon lesson. The same lesson delivered to a younger, less educated cohort might be simplified by discussing just two key concepts, which can then be increased in complexity as understanding improves and learning progresses, in a linear relation of one concept to another.

The concept table worked well for the purpose of identifying how the Lac Operon lesson might be broken down into its component parts and this could also aid in eliminating any ambiguous links between concepts. Inadvertently, constructing the concept table helped to develop a self-awareness of ingrained science terminology and communication practices that could be improved upon and expressed in a more relatable manner. However, the process of populating the concept table proved time consuming as concepts can overlap and it became apparent that it would be too unwieldy for application to larger lessons, or to use on more than one lesson topic at a time. Therefore, although valuable to have explored during development of the KLS Lac Operon lesson, it is difficult to recommend it as a practical tool to others and was not used to structure or scale any subsequent lessons developed.

A significant amount of time was allotted toward identifying key concepts in the text that could be represented in pictorial format for the purpose of facilitating an onscreen KL assembly interaction. Ultimately, over thirty 2D simplified illustrations

were created in Adobe illustrator and imported into PowerPoint as separate, independent icons. In PowerPoint, the icons were assembled into a wide variety of biomolecular scenarios depicting various stages of gene regulation in the Lac Operon. These scenarios were exclusively depictive of the lesson content. To prevent icons within a whole scenario from being pulled apart, they were locked together as one using PowerPoint's 'group' command. Small text boxes could also be pulled out of shape but saving them as images from PowerPoint or illustrator and re-inserting them into the slide worked well to resolve this issue. Icons could be copied and pasted repeatedly to generate different molecular biology scenarios for assembly. Informal feedback was provided by peers on the appearance and ease of interaction for the initial icons and scenarios developed.

3.4 Materials

Please note, the following lessons and tasks evolved through testing amongst students and were optimised over time through pilot studies which will be covered in in-depth in Chapter 4.

3.4.1 The KLS Lac Operon lesson layout

The general layout of the KLS lessons within PowerPoint was designed for independent, remote use and included introductory instruction slides on how to navigate and interact with the lesson. A practice PowerPoint containing the first three instruction slides was emailed to students in advance to familiarise them with the delivery and format of the study (see Figure 3.2). Early iterations of the lesson contained six instructional slides which preceded the lesson note slides and included a title slide, a slide with a YouTube logo-hyperlink to an animated video lesson and a motivational slide reminding students that the learning tasks being tested were the subject under investigation, not the student's academic ability.

Scioptle
Optimising Learning of Science

Lac Operon Research Lesson

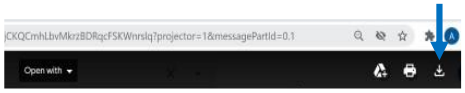
PowerPoint file



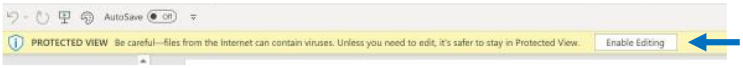
IMPORTANT! The email you received has a PowerPoint file attached.

If you clicked on the file, you may have opened it in Google slides rather than downloading it. Certain elements in this test will NOT work if opened in Google slides.

Therefore YOU MUST download the file:



Once downloaded, click 'Enable Editing' in the opened PowerPoint file:



Scioptle
Optimising Learning of Science

Dear Volunteer
Many thanks for participating in this research lesson into how science learning can be improved

The instructions for this lesson are outlined in the next few slides

Please read these instructions before you advance to the lesson

IMPORTANT: You will have received a unique 4digit code in the email containing this PowerPoint, which will be used to ensure your anonymity

Please insert this code in the box below

Insert your unique code here:

Scioptle
Optimising Learning of Science

Please note that this is an exercise to test a learning method- it is not testing your ability as a student

When completing the tasks, you are fully free to go back and forward between slides

Once you have completed the MCQ test, you will have completed the Lac Operon Research Lesson

Figure 3.2 Practice PowerPoint Instruction Slides. Students received these slides in advance of the main study to familiarise them with the delivery, layout and instructions.

The Flesch-Kincaid Grade Level was used to assess how easy the text of the lesson was to read. This system ranks text from 1 to 100, with the latter score indicating greater readability (URL 7). A grade level based on the US education system, is assigned to a Flesch ease of reading score. For example, a score between 60 - 70 indicates the text should be understood from the grade level of 8 upwards (typically from 13 years on). The number of paragraphs, sentences, words in a sentence and syllables in a sentence are taken into account to calculate the score and although equations were originally used, the calculations can now be done automatically in MS Word. The text for instructions contained 22 paragraphs, 27 sentences and was 657 words in length, with a Flesch-Kincaid ease of reading score of 63.8 and a reading grade level of 8.5.

The lesson notes and diagrams were identical for all study conditions and presented across 9 slides, including a bullet point recap slide. Lesson notes were written by a lecturer in biochemistry and the researcher. Lesson notes appeared on the left of each slide with pictorial illustrations created by the researcher matching the text on the right (see Figure 3.3). Excluding all headings and diagram labels, the lesson text contained 73 paragraphs, 66 sentences and was 1,550 words in length, with a Flesch-Kincaid ease of reading score of 58.7 and a reading grade level of 9.4.

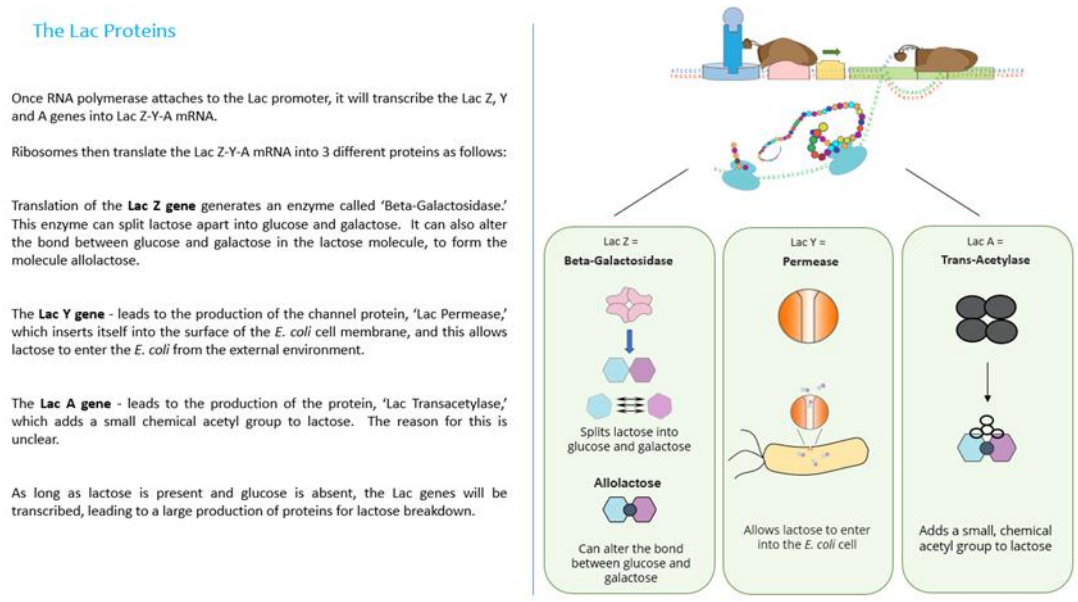


Figure 3.3 Sample PowerPoint slide from the Lac Operon lesson

For all conditions, students were advised to study the static lesson slide, complete the subsequent task slide and then recheck the previous lesson slide to see how accurate their knowledge was before proceeding to the next lesson slide. This constituted an immediate self-assessment and feedback instrument for the student, who could ascertain how well or not their recall and understanding of the previous lesson slide was, through their ability to complete the tasks assigned to them.
As the tasks were developed to reflect key concepts within the text of the lesson, students received focused content to clearly highlight expected learning outcomes, without the cognitive burden of extraneous details. Thus, the KLS lesson acts as a neutral tool that students can use outside the classroom for self-paced and self-directed study. Two slides containing instructions on how to access and proceed to the Google Form multiple choice question (MCQ) assessment concluded the PowerPoint. These instructions contained 17 paragraphs, 11 sentences and were 308 words in length, with a Flesch-Kincaid ease of reading score of 62.4 and a reading grade level of 9.7. These instructions were substantially reduced and presented on one slide in later iterations of the KL lesson.

3.4.2 KLS animated video

KLS Lac Operon experiments that were run from May 2020 to Oct-Nov 2020, included a bespoke Lac Operon video lesson (~12 mins) to precede the study of the lesson notes and was deemed important for several reasons. Mainly, the video was intended to mimic a one-time attendance at a lecture to reflect a realistic academic scenario, and to prime cognitive processing for optimum comprehension of the static lesson notes that followed. Choosing to show the video lesson in advance of studying the notes rather than afterwards, sought to achieve some of Mayer's cognitive goals for multimedia learning in relation to processing text and graphical content (Gegner et al., 2009) and with instructional guidelines for video use in mind (Bétrancourt & Benetos, 2018). The following link provides access to the Lac Operon video lesson in YouTube: https://tinyurl.com/Lacoperonvideo
Pairing the video with assembly tasks (although all conditions viewed it) was designed with Fiorella's 1st person perspective study in mind:

> *"the findings suggest that video modeling examples can be enhanced by presenting to-be-performed actions from the learner's own perspective" (Fiorella et al., 2017).*

As outlined in Chapter 2, first-person perspective involves watching the hands of another person from the viewpoint that one is looking down at one's own hands. The animated lesson does not use the visual of a hand so cannot be considered as viewing from a particular perspective. Instead, the icons used in the video lesson are the same icons used in the task slides and the flow of the animated sequences act like a preview for *"to-be-performed actions*" that the learner will have to complete if they are in one of the kinaesthetic groups. In having all groups view the animation, the non-kinaesthetic students receive the same advantage for visualising the flow of the biomolecular processes involved.

The lesson video was created by the researcher using PowerPoint's own animation features to animate the same pictures from the lesson into a slideshow format. A flowchart outlining the overall workflow for creating the video can be seen in Figure 3.4. This required all picture elements to be moveable independently of each other; in effect, they became picture icons that could be manipulated individually for animation. Narration for the video was recorded in Audacity using the same lesson notes as the transcript and was imported from Audacity into PowerPoint as a Wav. file. A separate Wav. file was necessary for each animated slide to record a fluid animation within PowerPoint.

The final slideshow file was exported as an MP4 video file directly into a dedicated YouTube channel (Scioptle: Optimising Learning of Science) set up for the purpose of the KLS study and by the approval of the Social Research Ethics Committee (SREC) in University College Cork (UCC). Thus, the video animation consisted of female voice narration paired with picture animation, without any text appearing on screen as recommended by Mayer's Principles of Multimedia (Clark & Mayer R, 2008). The video was further upgraded in later studies through Camtasia video editing software to include a musical intro with narrated instructions and an outro to bring the lesson to a definitive end.

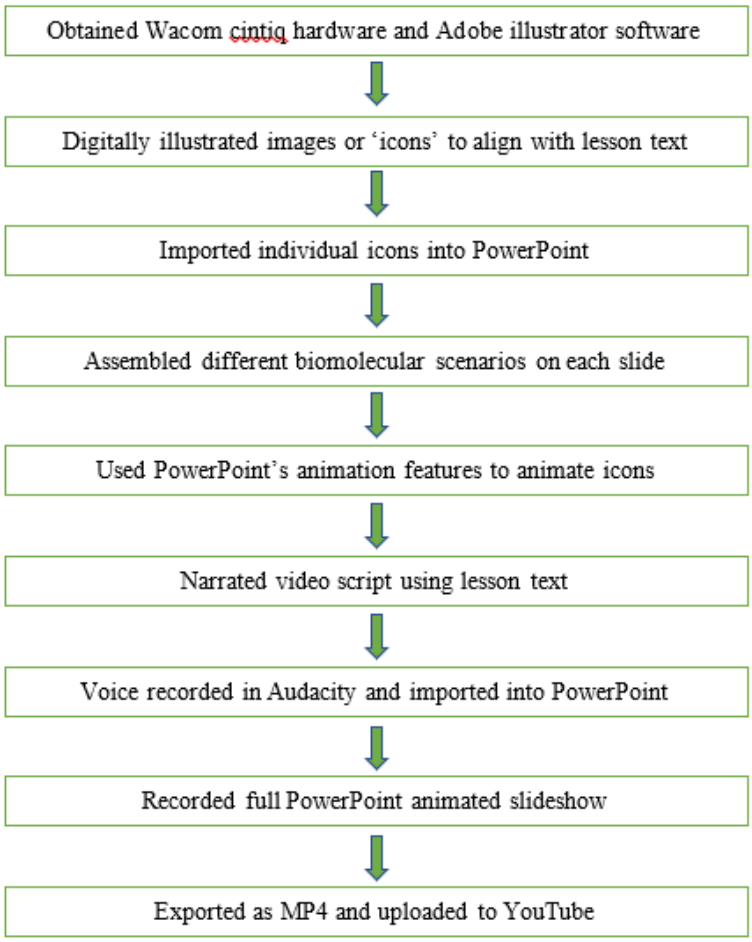


Figure 3.4 Workflow for designing and creating KLS lesson videos

3.4.3 KLS DNA Research Lesson

The KLS DNA Research Lesson used in the secondary schools' experiment was also created within PowerPoint, and as per the Lac Operon lesson was designed for independent, remote use. For ethical reasons, the lesson was delivered through the assistance of teachers who agreed to facilitate the study during class time. There was no direct contact between students and the researchers. Teachers received detailed written (and verbal where necessary) instructions on delivery and supervision of the lesson, including a video with instructions for teachers, which can be accessed through the following link: https://www.screencast.com/t/OpJgD6too. Teachers were advised that the study timing was suitable to run as a single class but that a double class would allow for any unforeseen technical issues to be resolved. This process is discussed in more detail in Chapter 4 under *Experiment 7*.

The topic of DNA transcription and translation is generally covered in the 5th or 6th year of the senior cycle to a lesser degree than content covered by the DNA

research lesson and was deemed a suitably challenging topic of relevance for the secondary schools and of benefit for students. It contained three introductory slides which preceded the lesson note slides, comprising a title slide, one instructional slide and the same motivational slide used with the Lac Operon lesson. The text for instructions contained 7 paragraphs, 12 sentences and was 197 words in length, with a Flesch-Kincaid reading ease score of 69.6 and a reading grade level of 7.2. The lesson notes and diagrams were identical for all study conditions and presented across 7 slides, including a bullet point recap slide. Lesson notes were written by the researcher, including illustrations and videos. Notes appeared on the left of each slide with pictorial illustrations matching the text on the right, except for one slide in which text appeared at the top, with matching pictorial illustrations underneath (see Figure 3.5).

Excluding all headings and diagram labels, the lesson text contained 36 paragraphs, 72 sentences and was 1,276 words in length, with a Flesch-Kincaid reading ease score of 65.7 and a reading grade level of 8.8. For all conditions, students were advised to study the static lesson slide, complete the subsequent task slide, and then recheck the previous lesson slide to see how accurate their knowledge was before proceeding to the next lesson slide. One slide containing instructions on how to access and proceed to the Google Form multiple choice question (MCQ) assessment concluded the PowerPoint. These instructions contained four paragraphs, three sentences and was 65 words in length, with a Flesch-Kincaid reading ease score of 70.9 and a reading grade level of 8.3. A short DNA Research video animation (~8 mins) was produced in the same manner as the Lac Operon lesson, using the same icons within the DNA Research Lesson to animate the video.

No text appeared in the video but the exact text from the lesson was used as the transcript for narration. The following link provides access to the DNA Research Lesson video in YouTube: https://tinyurl.com/dnalessonvid The initial advice to teachers was to play the video lesson on DNA transcription and translation within the classroom.

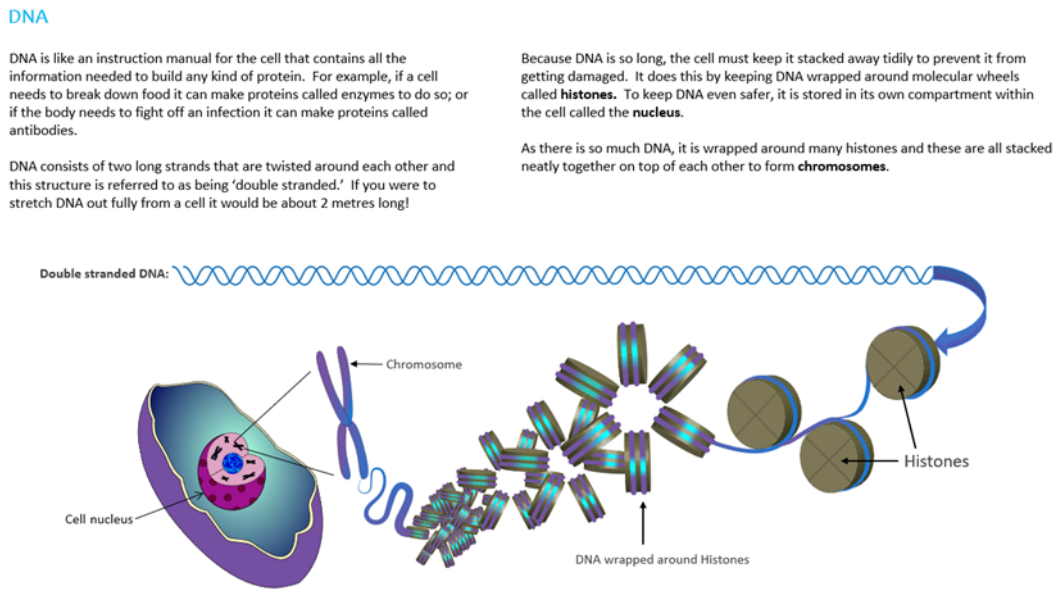


Figure 3.5 Sample PowerPoint slide from the DNA Research Lesson

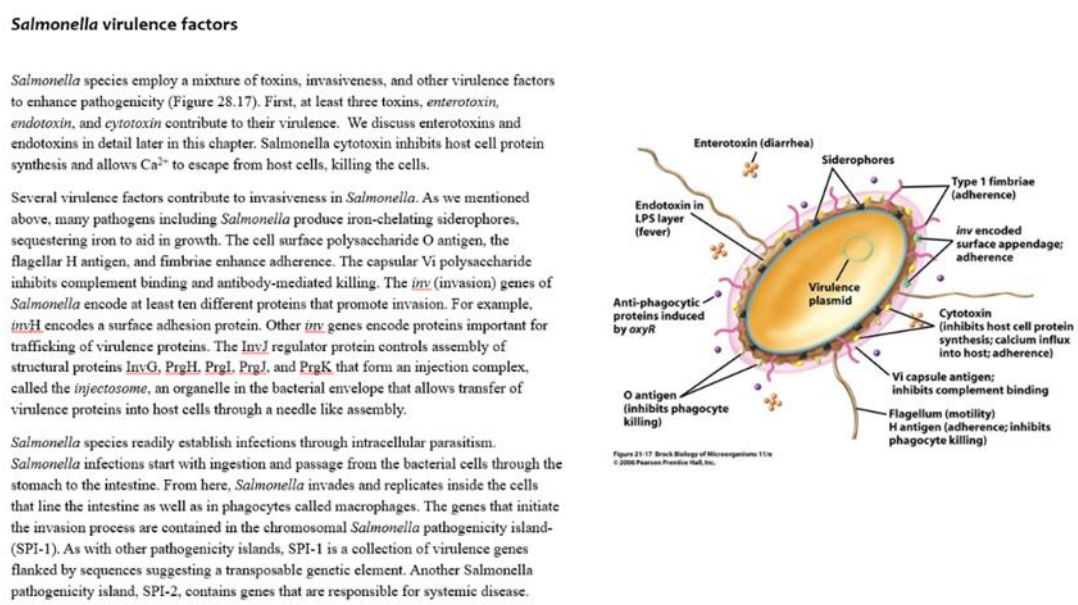
However, given that Covid was leading to staff and student absenteeism, it was also possible to play the video live online to the class should any teacher or student be participating from home. An MP4 version of the same video was also provided where schools preferred not to use YouTube. Teachers were advised to download and play the video on a shared screen for students, or to provide them with the MP4 via email on the day of testing – whichever option was most suitable.

3.4.4 KLS Science Taster Lesson

As with the previous lessons, the layout of the KLS Science Taster Lesson within PowerPoint was designed for independent, remote use. The chosen topic was based on Salmonella virulence factors and was considerably shorter than the previous KLS lesson formats, containing 3 slides for the neutral control condition and 4 slides for conditions with a task slide. The text for the introductory instructions contained four paragraphs, seven sentences and was 134 words in length, with a Flesch-Kincaid reading ease score of 50.1 and a reading grade level of 10.9.

The lesson notes and diagram were identical for all study conditions and presented on 1 slide. Lesson notes appeared on the left slide with a pictorial illustration of a salmonella bacterium matching the text on the right (see Figure 3.6).

The text for the lesson notes was taken as printed from pg. 826 of '*Brock Biology of Microorganisms, Twelfth Edition'* by Madigan, Martinko, Dunlap and Clark (2009) and with permission from the publisher. This book is recommended reading for senior undergraduate microbiology students. The image used was taken from the same page and redrawn digitally in Adobe illustrator by the researcher in compliance with copyright regulations for educational use, to be separable into multiple sub-components. This meant they could be pieced together into a whole picture or pulled apart. The purpose of taking the notes and illustration directly from a textbook was to demonstrate how KLS can be applied to existing educational content at a highly advanced level and again, to determine how expandable the framework is for different levels of knowledge.



***Salmonella* virulence factors**

Salmonella species employ a mixture of toxins, invasiveness, and other virulence factors to enhance pathogenicity (Figure 28.17). First, at least three toxins, *enterotoxin, endotoxin*, and *cytotoxin* contribute to their virulence. We discuss enterotoxins and endotoxins in detail later in this chapter. Salmonella cytotoxin inhibits host cell protein synthesis and allows Ca^{2+} to escape from host cells, killing the cells.

Several virulence factors contribute to invasiveness in *Salmonella*. As we mentioned above, many pathogens including *Salmonella* produce iron-chelating siderophores, sequestering iron to aid in growth. The cell surface polysaccharide O antigen, the flagellar H antigen, and fimbriae enhance adherence. The capsular Vi polysaccharide inhibits complement binding and antibody-mediated killing. The *inv* (invasion) genes of *Salmonella* encode at least ten different proteins that promote invasion. For example, *invH* encodes a surface adhesion protein. Other *inv* genes encode proteins important for trafficking of virulence proteins. The InvJ regulator protein controls assembly of structural proteins InvG, PrgH, PrgI, PrgJ, and PrgK that form an injection complex, called the *injectosome*, an organelle in the bacterial envelope that allows transfer of virulence proteins into host cells through a needle like assembly.

Salmonella species readily establish infections through intracellular parasitism. *Salmonella* infections start with ingestion and passage from the bacterial cells through the stomach to the intestine. From here, *Salmonella* invades and replicates inside the cells that line the intestine as well as in phagocytes called macrophages. The genes that initiate the invasion process are contained in the chromosomal *Salmonella* pathogenicity island-(SPI-1). As with other pathogenicity islands, SPI-1 is a collection of virulence genes flanked by sequences suggesting a transposable genetic element. Another Salmonella pathogenicity island, SPI-2, contains genes that are responsible for systemic disease.

Figure 3.6 Sample PowerPoint slide from Science Taster Lesson

No background information was provided to scaffold understanding for the lesson or for the science terminology, although an index was included in the grey 'Notes' section of the lesson slide to clarify various terms, e.g., "**Chelating** – binding together of a metal and chemical compound to form a ring." The goal was to ascertain whether any KLS task had the ability to link concepts faster for a deeper understanding, especially in cases where educational material is poorly presented or not supported adequately for the learner. Hence, it was delivered completely randomly to post-graduate students without a pre-requisite for prior science, but

neither did it exclude those who had. Although short in length, it was an exceptionally challenging topic and the most difficult lesson format devised for the KLS study.

Excluding all headings and diagram labels, the lesson text contained three paragraphs, eighteen sentences and was 279 words in length, with a Flesch-Kincaid reading ease score of 14.9 and a reading grade level of 15. For all conditions, students were advised to study the static lesson slide, complete the single task slide, and then recheck the previous lesson slide to see how accurate their knowledge was. One slide containing instructions on how to access and proceed to the Quiz 1 (Google Form MCQ) assessment concluded the PowerPoint. These instructions contained three paragraphs, four sentences and were 63 words in length, with a Flesch-Kincaid ease of reading score of 52.4 and a reading grade level of 10.6.

3.5 Designing the KLS groups

The task slides specific to each PowerPoint comprised the different conditions being tested for the KLS study. Not all conditions were tested across all experiments as this was an inductive study which grew very much from an idea, involved extensive analysis and re-evaluation of the various conditions, and subsequently improved upon their presentation and implementation within PowerPoint for an optimised KLS lesson format. The title of study groups for the KLS experiments were all abbreviations of the conditions being tested and the 'K' in the title of each condition simply links them back to the KLS framework as having achieved the desired criteria to proceed to testing:

i. Unguided Assembly: interactive assembly requiring movement and recall. Students clicked and dragged a selection of independent icons arranged at the top or side of each task slide into a blank space, to assemble a whole diagram depicting key molecular processes from the previous lesson slide (see Figure 3.7 a, b & c). This mimicked kinaesthetic assembly through model/circuit building and involved an element of trial-and-error practice.

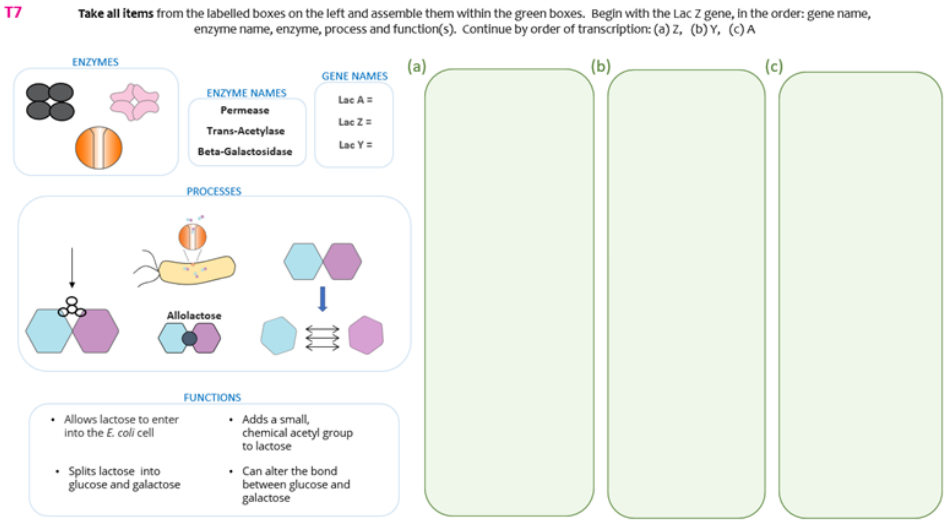


Figure 3.7 (a) Sample Unguided Assembly task from Lac Operon lesson

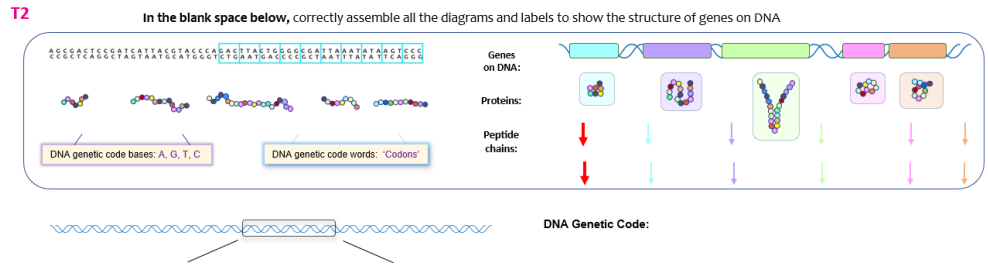


Figure 3.7 (b) Sample Unguided Assembly task from DNA Research lesson

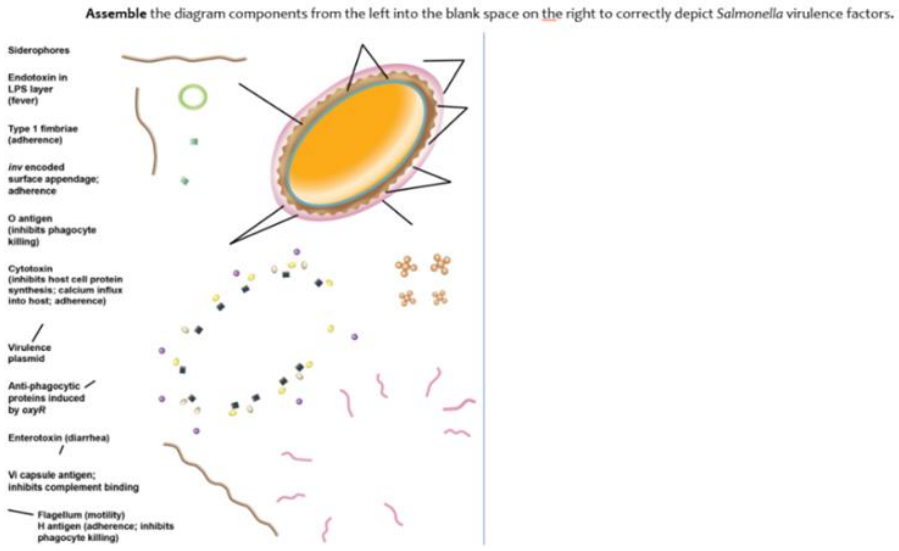


Figure 3.7 (c) Sample Unguided Assembly task from Science Taster lesson

ii. Guided Assembly: interactive assembly requiring movement only. Students moved items into place to assemble a whole diagram, except no recall was required as the independent icons were guided for assembly over a neutral coloured/greyed out, fully assembled picture (see Figure 3.8 a, b & c). As with the previous condition, kinaesthetic assembly through model building was mimicked but trial and error practice did not feature.

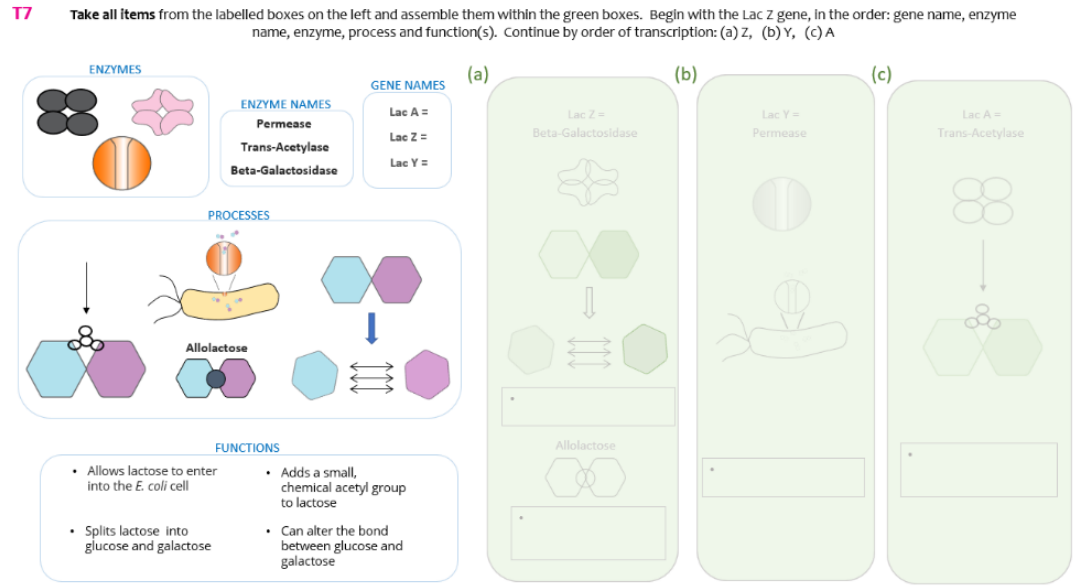


Figure 3.8 (a) Sample Guided Assembly task slide from Lac Operon lesson

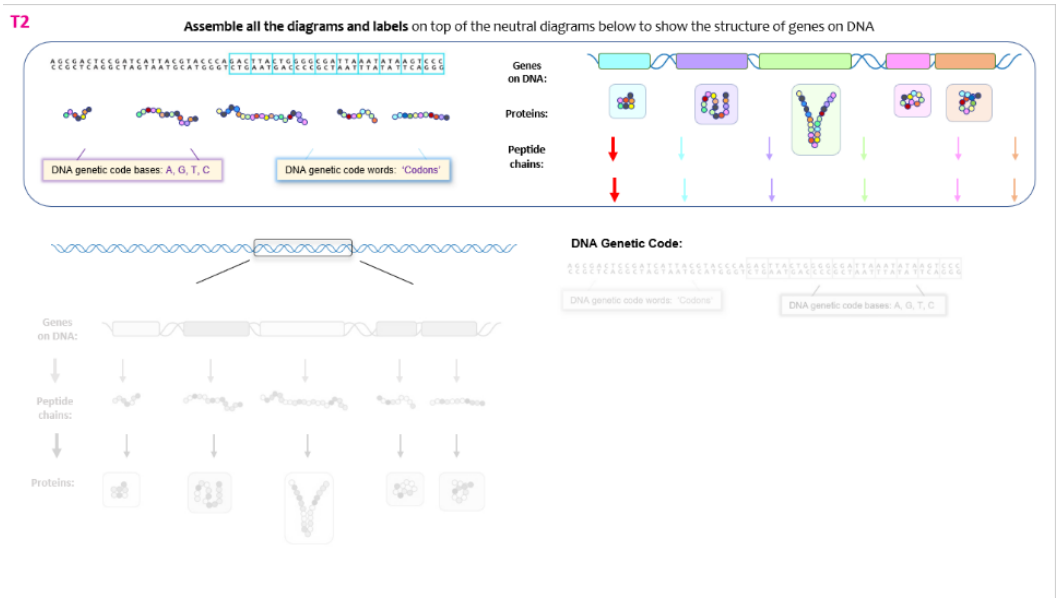


Figure 3.8 (b) Sample Guided Assembly task slide from DNA Research lesson

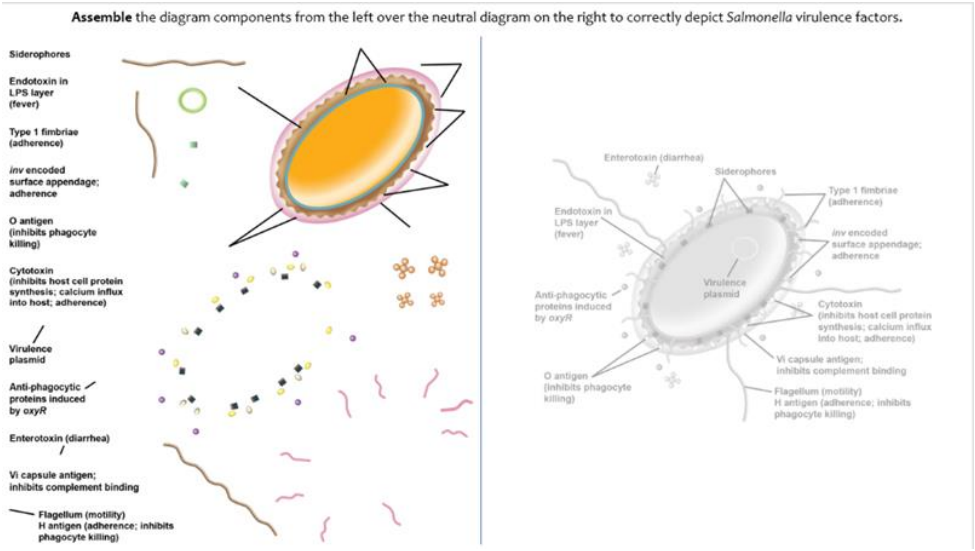


Figure 3.8 (c) Sample Guided Assembly task slide from Science Taster lesson

iii. Mental Assembly: non-interactive diagrams based on identification of correct from incorrectly assembled diagram scenarios. Scenarios were presented in numbered boxes and students were instructed to identify the correct scenarios by typing the number of the boxes into the 'Notes' section at the base of each task slide (see Figure 3.9 a, b & c). Even though no movement was required, this could possibly be considered kinaesthetic as students had to internally visualise or mentally assemble the correct versions in their mind in order to recall and identify it from the incorrect versions.

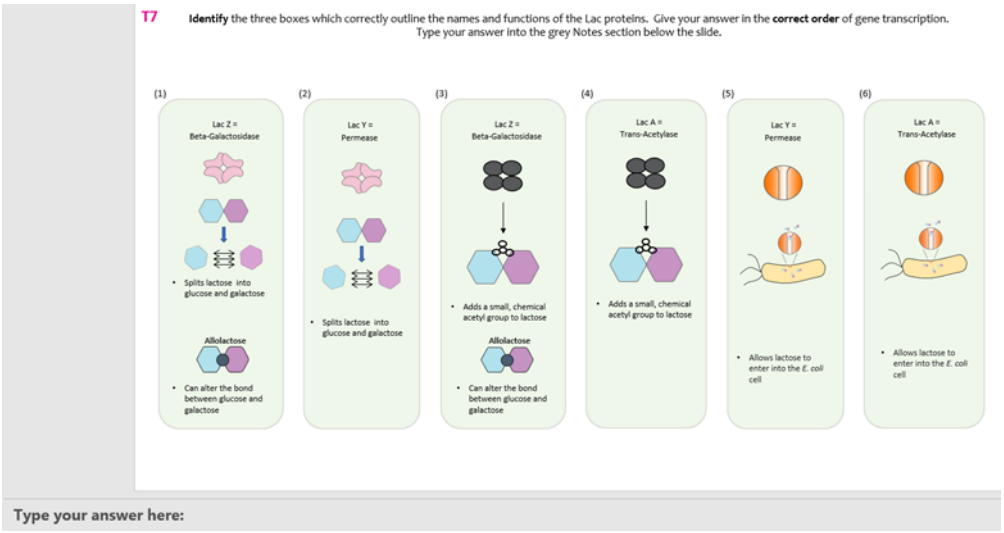


Figure 3.9 (a) Sample Mental Assembly task from Lac Operon lesson

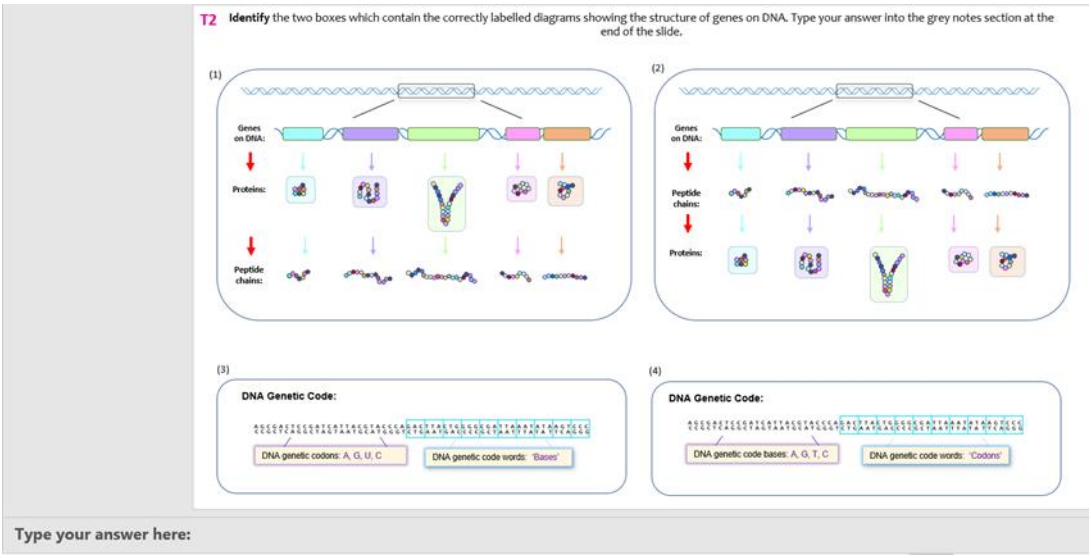


Figure 3.9 (b) Sample Mental Assembly task from DNA Research lesson

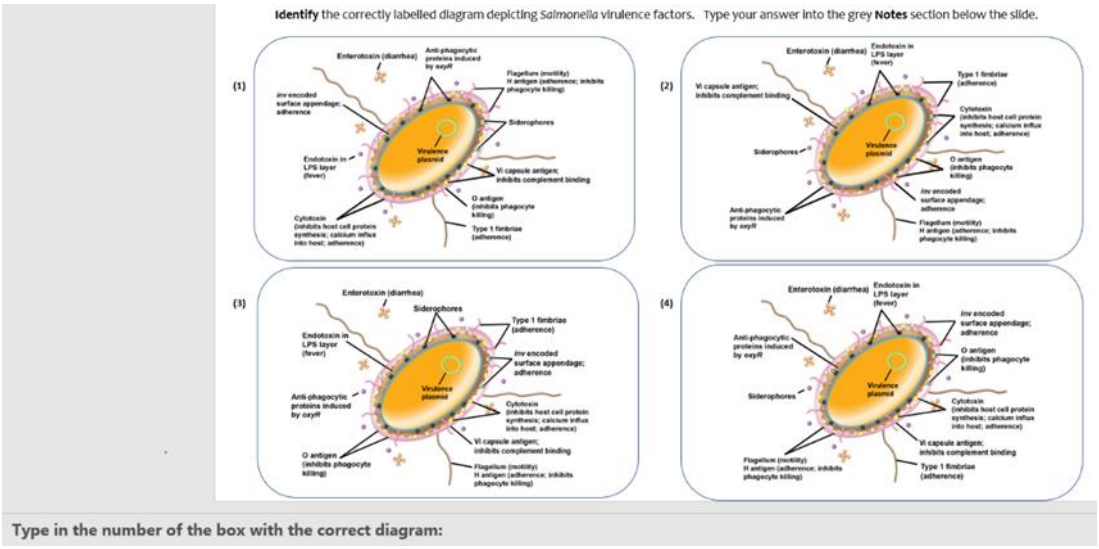


Figure 3.9 (c) ***Sample Mental*** ***Assembly task from Science Taster lesson***

iv. Question Guided Recall: recall in which students typed the answers (short or bullet point) to 6/7 questions posed in task slides to cue recall for key points in the previous lesson slide (see Figure 3.10). Cued recall is known to be effective for learning (Brame & Biel, 2015; Schneider, Beege, Nebel & Rey, 2018) as is repeat 'retrieval practice' (Karpicke & Blunt, 2011) and this condition was initially used as a comparison for guided and unguided assembly in the first large sample study using two-timepoints.

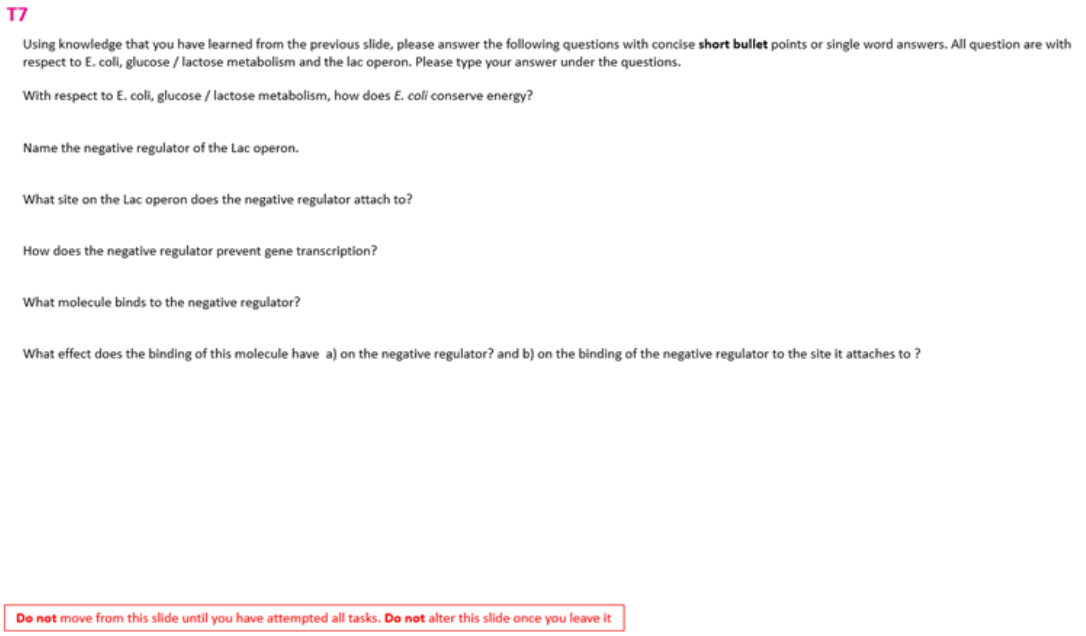


Figure 3.10 ***Sample Question Guided Recall task from Lac Operon***

v. Free Recall: free recall in which students typed as much information as they could remember in their own words, from the previous lesson slide, into a blank box in the task slide (see Figure 3.11). Free recall is known to be effective for learning and replaced Question Guided Recall as a tighter comparison for Unguided Assembly in later experiments.

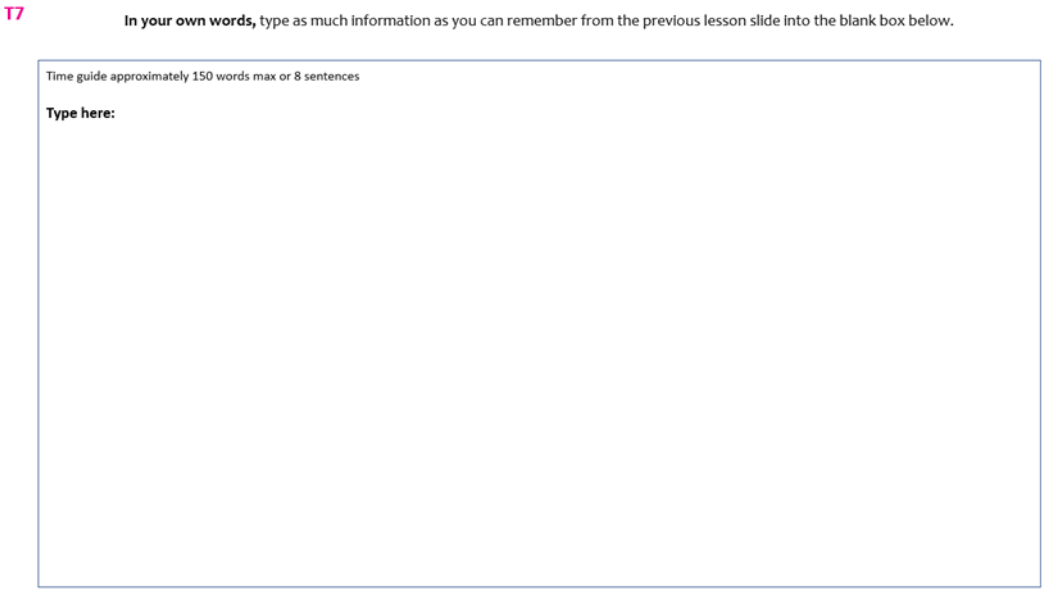


Figure 3.11 ***Sample Free Recall Task Slide.*** This was almost identical for all lessons.

vi. Neutral: students did not receive any task slides and were instructed to memorise each lesson slide before proceeding to the next slide (see Figure 3.12 a, b & c). This was akin to 'cramming' as students had to memorise a lesson under time pressure while aware an exam would follow. As the group did not employ any learning techniques beyond focused memorisation, they were also considered the baseline control in later experiments for Unguided Assembly and Free Recall.

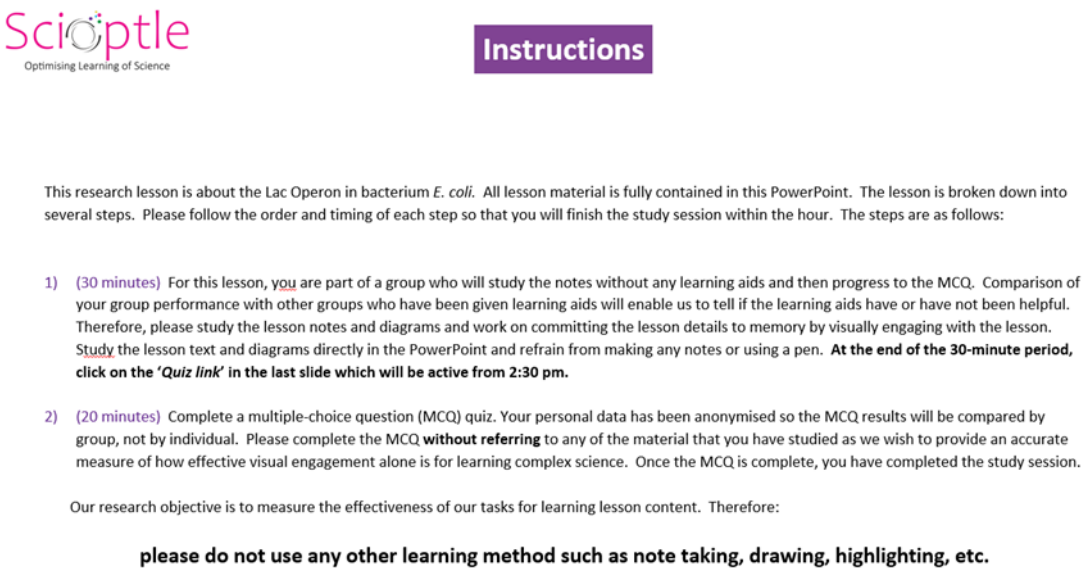


Figure 3.12 (a) Sample Neutral instruction slide from Lac Operon lesson

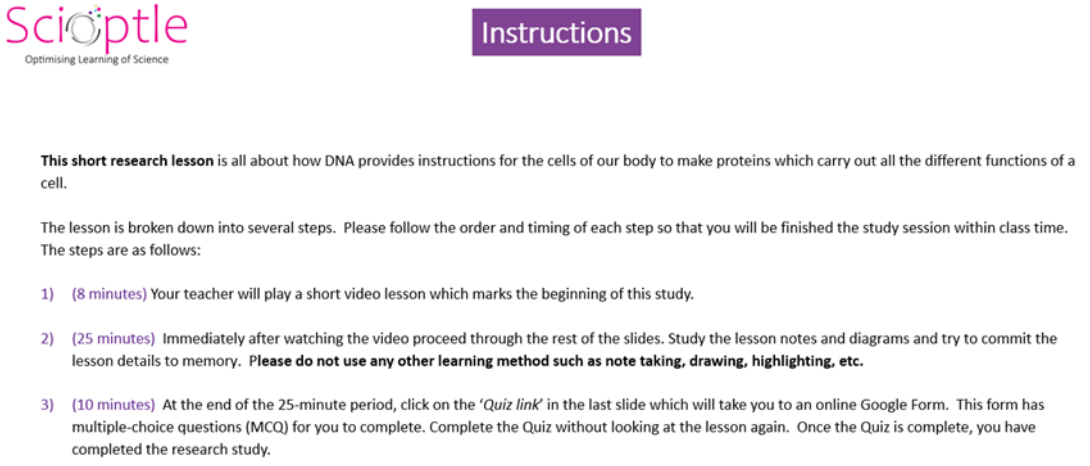


Figure 3.12 (b) Sample Neutral instruction slide from DNA Research lesson

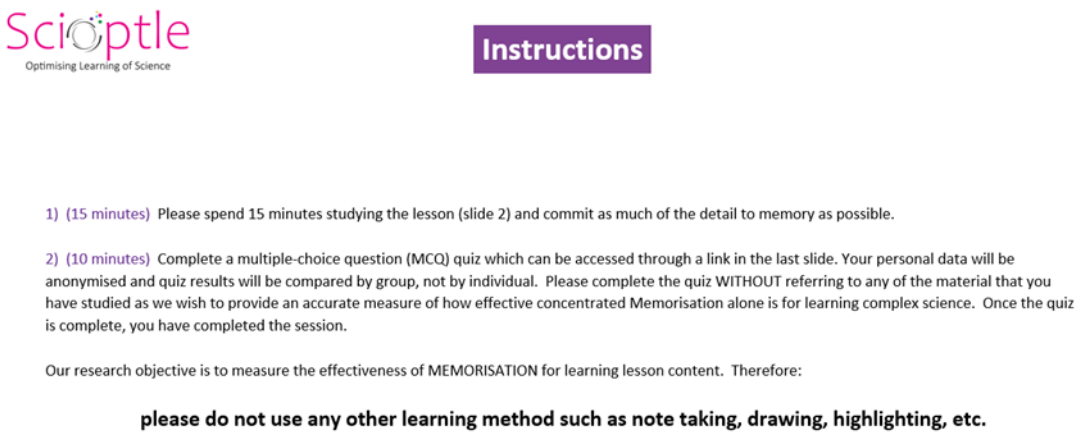


Figure 3.12 (c) Sample Neutral instruction slide from Science Taster lesson

Illustrations on task slides for the unguided and guided assembly conditions were moveable for assembly through use of a trackpad, mouse, or touchscreen whereas illustrations were locked onscreen for Mental Assembly. Kinaesthetic learning requires both a recall aspect and a movement aspect and a novel approach taken was to test whether one aspect was more dependent on the other for knowledge retention and understanding. Hence, the Unguided Assembly group required both movement and recall, while the Guided Assembly group required movement without recall.

The presentation of correctly assembled vs. incorrectly assembled diagrams in the Mental Assembly group required recall without movement and is more pictorial than text-based to better match the unguided and guided assembly conditions. Static illustrations on their own may not aid the students' understanding of the temporal order of biochemical processes, or the visual alteration/function of molecules involved unless also presented as an animation. However, presenting a selection of correct and incorrectly assembled biomolecular scenarios would provide more of a challenge, requiring the student to mentally piece together the various scenarios in order to screen the correct from the incorrect. In designing the unguided and guided assembly groups, it was also hoped to observe whether the construction of biochemical scenarios can compensate for a lack of animation or lecture presence.

The Question Guided Recall, Free Recall and Neutral conditions did not contain any illustrations in the task slides and the approach to learning was inspired by the retrieval-practice condition (study, free recall, study, free recall) used by Karpicke and Blunt (2011). In Karpicke's retrieval-practice, students studied a

science text on sea otters (276 words) for 5 min, after which a response box appeared onscreen. These students then practiced retrieval for 10 min, by typing as much of the information as they could recall into the box. The 5 min study and 10 min retrieval practice were repeated for a second time, in what amounted to a total study session time of 30 min.

Students in the Question Guided Recall condition of the KLS study were advised they had 30 minutes in which to study 9 lesson slides and complete 9 task slides. The task slides posed a set of 6 to 7 questions relating to key points from the previous lesson slide. Because the text of the Lac Operon lesson was significantly longer and more difficult than 'Sea Otters,' students were advised to study the lesson slide, complete the questions posed in the task slide (bullet points or short answers) and then restudy the lesson slide briefly before proceeding to the next lesson slide without altering their answers. However, self-testing through practicing questions has a powerful effect on long-term retention in what is generally referred to as the 'testing effect' (Roediger & Karpicke, 2006; Brame & Biel, 2015) and there was initial uncertainty about using this format as a suitable comparison to the highly novel, illustration-based assembly test groups. Concept mapping would have been a closer comparison due to the illustrative qualities involved but as this approach has repeatedly proven less effective than retrieval-practice (O'Day et al., 2021), the question guided recall format was accepted as a comparison condition.

The Free Recall task slides contained a response box into which students were instructed to use their own words to type in whatever they could remember from the previous lesson, similar to the tested practice of taking free-form notes on a computer in the learner's own words (Camfield, McFAll & Land, 2016). The type of note taking students employ can influence learning differentially (Bui, Myerson & Hale, 2013; Chi & Wylie, 2014). Highlighting notes/text using a computer is considered a note taking related strategy that serves to focus the learner on chunks of key information at a time and has proven effective for learning compared to passive study approaches, such as reading or listening to a lecture. Still, active note taking strategies such as highlighting or copying and pasting content, are still less effective compared to constructive note taking. They also establish that the most effective learning strategies involve an element of peer interaction or interactive engagement, but comparatively fewer studies exist to truly judge the effectiveness of collaboration. As one of the objectives in developing the KLS framework was to

enable online self-paced, self-directed study, the collaborative element afforded by in-class attendance was necessarily removed. However, any KL lesson developed would not preclude collaboration in a real-world application of its use in academia.

Under Chi & Wiley's ICAP framework (cf. section 2.1.6), the Neutral condition could at first be thought of as a passive learning approach. Rereading notes is considered a passive strategy with no statistically significant benefits to learning unless done with deliberate concentration in a repeated pattern as per, for example, Karpicke's retrieval practice condition. However, for the KLS study, students were asked to actively memorise content in a simulation of 'cramming' or rote-learning, a common practice that students engage in prior to an exam.

3.6 Learning Outcomes for the three KLS lessons

Learning outcomes were written to align the three different KLS lessons, (the Lac Operon lesson, the DNA Research Lesson and the *Salmonella* Science Taster lesson) to Bloom's Taxonomy tiers and categories of learning, as outlined in section 3.3.1. These are presented as three separate tables in the following pages and include all final optimised study conditions tested. The cognitive domain is the best-known category of Bloom's taxonomy and is typically the only one that appears in images relating to the taxonomy. However, all three categories of Bloom's taxonomy are included in the learning outcome tables for each lesson. The psychomotor domain was of particular relevance for the development of the KL study tasks.

Table 3.4 Learning Outcomes for the Lac Operon Lesson

Bloom's Taxonomy Level	Cognitive Domain Learning Outcomes
L3. Application	– Categorise and order the structural components of the Lac Operon.
L4. Analysis	– Connect the function of regulatory molecules with their binding sites and temporal order, in response to sugar type.
L5. Synthesis	– Relate changes in the presence of glucose and lactose to positive and negative regulation.
L6. Evaluate	– Predict the outcome for regulation and function of the Lac Operon given a variety of novel hypothetical scenarios to demonstrate knowledge transfer.
	Affective Domain Learning Outcomes
	– Complete all aspects of the study as directed by researcher and in compliance with study parameters and ethical standards.
	– Provide insight and guidance on the design, delivery and assessment of the KL lesson and quiz.
	Psychomotor Domain Learning Outcomes
Unguided Assembly:	– Assemble onscreen diagrams to depict multiple biomolecular scenarios.
Guided Assembly:	– Assemble onscreen diagrams to depict multiple biomolecular scenarios.
Question Guided Recall:	– Outline key concepts onscreen using question guided recall.
Mental Assembly:	– Discriminate between correct and incorrectly assembled biomolecular scenarios.
Free Recall:	– Rewrite lesson in own words using free recall of learned content.
Neutral:	– Memorise key concepts without the use of additional learning aids.

Table 3.5 Learning Outcomes in relation to the DNA Research lesson

Bloom's Taxonomy Level	Cognitive Domain Learning Outcomes
3. Application	– Differentiate between transcription and translation.
	– Categorise and differentiate between DNA, mRNA, genes, amino acids and proteins.
	– Match the nucleic acid bases correctly and differentiate between bases, codons and genes.
4. Analysis	– Connect the function and temporal order of regulatory molecules to DNA transcription and translation, including RNA polymerase, ribosomes and tRNAs.
6. Evaluate	– Predict the outcome for DNA transcription and translation given a variety of novel, hypothetical scenarios to demonstrate knowledge transfer.
	Affective Domain Learning Outcomes
	– Complete all aspects of the study as directed by researcher, the class teacher and in compliance with study parameters and ethical standards.
	– Teacher to relay insights and guidance on the design, delivery and assessment of the KL lesson, tasks and quizzes.
	– Manage competing demands on time for studying the DNA Research Lesson, completing all assigned tasks and self-assessing knowledge in order to self-direct learning in under 30 mins.
	Psychomotor Domain Learning Outcomes
Unguided Assembly:	– Assemble onscreen diagrams to depict multiple biomolecular scenarios.
Guided Assembly:	– Assemble onscreen diagrams to depict multiple biomolecular scenarios.
Free Recall:	– Rewrite lesson in own words by freely recalling the lesson content.

Mental Assembly:	– Discriminate between correct and incorrectly assembled biomolecular scenarios.
Neutral:	– Memorise key concepts without the use of additional learning aids.

Table 3.6 Learning Outcomes in relation to the Science Taster lesson

Bloom's Taxonomy Level	Cognitive Domain Learning Outcomes
3. Application	– Identify the structural components of Salmonella
4. Analysis	– Differentiate between invasion genes and the proteins they encode.
5. Synthesis	– Explain the infection mechanism employed by Salmonella.
6. Evaluate	– Predict the outcome for Salmonella pathogenicity and disease given a variety of novel, hypothetical scenarios.
	Affective Domain Learning Outcomes
	– Complete all aspects of the study as directed by researcher & in compliance with study parameters & ethical standards.
	– Manage competing demands on time for studying the Salmonella Science Taster lesson, completing all assigned tasks and self-assessing knowledge in order to self-direct learning in under 15 mins.
	Psychomotor Domain Learning Outcomes
Unguided Assembly:	– Assemble onscreen diagrams to depict multiple biomolecular scenarios.
Guided Assembly:	– Assemble multiple biomolecular scenarios over neutral pre-assembled diagrams.
Free Recall:	– Rewrite lesson in own words by freely recalling the lesson content.
Neutral:	– Memorise key concepts without using additional learning aids.

3.7 Predicted Impact

For the educator, ideally the KLS lesson layout would facilitate an overview at a glance, for how well an individual student was grasping key concepts in the lesson if employing a specific KLS approach. Hence, it was imperative that the learning outcomes be quantifiable to reflect whether employing a specific KL approach would be generalisable to different knowledge levels, different science lesson content and whether it would have predictive validity for grade outcome. If successful, the KLS could provide a framework toward the ongoing research, translation and development of KL approaches into online lessons for complex science topics in a highly assessable, adaptable and reproducible format not currently met in education.

For this purpose, a means of evaluating the KLS framework using both semi-structured, qualitative data and objective quantitative measures was developed in line with established methods of research in education (Wellington, 2000; Cohen et al., 2007) and with Mayer's e-learning principles in mind (Clark & R. Mayer, 2008). Based on insights gleaned from the literature review of Chapter 3, a set of reference points emerged (section 3.7.1) to structure these measures and to ensure that KL approaches could be scrutinised academically for learning through valid assessment formats, e.g., multiple choice questions (MCQs), short answer questions (SAQs) and multi-select questions (MSQs). In particular, these reference points serve to align evidence-based learning and assessment approaches to the KL and assessment model of the KLS (section 3.2.6). This assessment model complemented the initial evaluation criteria for development of the KLS (section 3.3.1) and helped to inform the direction and evolving experimental design of KL lessons, study conditions, data collection and analysis.

3.7.1 Assessment of the KLS framework:

- Evaluate a simple model through initial pilot studies which can be increased or decreased in complexity.
- Compare test groups (kinaesthetic interaction within an online lesson) vs. a control group (no kinaesthetic interaction with identical online lesson).

- Assess realistically via MCQs, SAQs and/or MSQs to measure recall of details and transfer knowledge for hypothetical scenarios (Makransky et al., 2021).
- Use individual, anonymised study codes to maintain student anonymity and provide objective grading online in Google Form generated quizzes.
- Assessment must match the grade level and difficulty of the lesson.
- Test KLS in a real-world context for ecological and content validity (Clark & Mayer, 2008; Sankey et al., 2011; Price et al., 2022).
- Return to subject matter at a later date to provide a true assessment of long-term learning (De Jong, 2010; Korbach et al., 2016; Camina & Guëll, 2017).
- Invite feedback to align quantitative results with qualitative data (Wellington, 2007).
- Predictive validity - group mean comparison to indicate how any approach may perform in future applications of KLS to science lessons.

The key aspect of assessment and evaluation would focus on determining if the students had developed:

(a) Deep understanding as determined by transfer testing.

(b) Short-term learning as determined by post-test knowledge recall MCQs.

(c) Long-term knowledge retention as determined by a second timepoint multi-select MCQ incorporating both recall and transfer questions.

(d) More attentive behaviour to online lessons with less tendency toward distraction as determined by student feedback - to include in at least one study, the return of PowerPoints.

Qualitative feedback would help facilitate the ongoing progression of prototype KL lessons as a tool for self-directed learning, self-assessment and/or formative assessment, feedback and delivery, into the KLS framework. Learning outcomes would be quantified using exams of comparable difficulty to the KL lesson content, to truly test the effectiveness of the KLS.

3.8 Summary

This chapter focused on the steps taken to meet the objectives of identifying, designing and developing suitable kinaesthetic approaches for translation to an online platform. The KL practice of assembling a model was deemed most appropriate and was designed to examine, (a) whether KL relies on both the experiential action with active recall (unguided movement/manipulation of icons = Unguided Assembly), (b) whether KL relies more on an action which is experiential without focusing on recall (guided movement/manipulation of icons = Guided Assembly) or (c) whether recall alone is sufficient if challenged with a mental assembly task that does not require any physical manipulation/movement of icons (discriminating between correct and incorrectly assembled diagrams using recall alone = Mental Assembly). The latter holds potential in particular for learners who may be physically impaired and who may not be able to benefit from onscreen interactive approaches.

Part of meeting the objectives was to employ suitable software both to create and facilitate the development, hosting and use of an online KL assembly approach. PowerPoint proved to be highly flexible and user friendly for enabling a lesson layout that could implement a broad range of research-based best practice e-learning guidelines. The KL PowerPoint lesson format was agile enough that lessons could be constructed within it to suit different knowledge levels (scalable) and for ease of online delivery on students' own devices and for different science topics (expandable). This meets a call from science and education research to provide more continuity across tiers of education. Another important research observation addressed is the need for more innovative formative assessments that can mitigate the negatives and/or reduce the reliance on the high-stakes summative assessment model. This is achieved in the layout of the KL assembly PowerPoint by having task slides interspersed with lesson slides throughout the full PowerPoint, thus providing the student with a simple means of self-assessment checks that can be self-paced and self-directed as they progress through the lesson.

CHAPTER 4

RESEARCH METHODOLOGY

4.1 Introduction

The overarching aim of this thesis is to investigate the extent to which it is possible to translate a typical kinaesthetic approach, such as assembling a model, into an online KL approach for learning molecular science. The design of the KL assembly approach was completed through the onscreen assembly of individual, movable icons into whole scenarios depicting the flow and temporal order of various molecular and biochemical processes. A total of eight trial teaching and learning activities were carried out. In this thesis, each of these teaching and learning activities will be referred to as an "experiment." This short chapter presents an overview of the methodological set-up for all experiments conducted during the thesis. Because of the large number of experiments and progressive nature of methodology arising from the results of each, the experiments are presented as distinct chapters, from chapters 5 through to 10, with Chapter 5 encompassing the three pilot studies. Each experiment chapter includes the results, conducted using a mixed-methods approach, and discusses the experimental outcomes both quantitatively and qualitatively.

Ethical approval for the design, implementation, analysis and presentation of all experiments reported was received in advance from the Social Research Ethics Committee in UCC. Anonymity of participant's grades at individual level was specified and thus, no data which could identify a student with their grade will be presented in this thesis or in the Appendix. Secondary schools who participated were given the same reassurance and consequently, secondary school data is not presented at an individual school level.

4.1.1 Aims of study

- *Test the KL lessons as realistically as possible.*
- *Evaluate the feasibility of presenting a full one-hour lecture as an online lesson for synchronous self-directed learning in less than 30 mins.*

- *Ensure the language and graphics of the KL lesson are not confounding factors to learning molecular science.*
- *Assess whether the presentation of movable icons within PowerPoint is feasible as a learning technique, whether delivered on campus or remotely for self-directed learning of molecular science.*
- *Determine whether online kinaesthetic learning approaches are better for learning than non-kinaesthetic learning approaches.*
- *Assess whether the KLS is scalable for application to different knowledge levels and expandable for delivery by third parties.*

For each experiment chapter, the list of teaching objectives will be listed first, followed by a table showing the constructive alignment (Biggs, 2003) between the learning outcome, the teaching and learning activities (T&L) and the assessment for each of the research lessons, i.e., the Lac Operon lesson, the DNA Research Lesson and the *Salmonella* Science Taster lesson (see Table 5.1, the first of 3 tables). Constructive alignment ensures that assessments can provide a suitable measure of the T&L and that both the T&L and assessments support the student to achieve the specified learning outcomes. Learning outcomes were formatted as outlined in Chapter 3.

Initial exploratory pilot studies conducted during a single study session were scaled up to larger studies for statistical analysis and tested students over two timepoints: an initial study session followed by immediate post-testing Timepoint 1 (T1) and a follow-up post-test seven days later Timepoint 2 (T2). Boxplots relating to seven of the experiments are presented throughout, with statistical significance indicated by: * ($p < 0.05$), ** ($p < 0.01$), *** ($p < 0.001$). SPSS output tables for experiments 4 to 8 are provided in Appendix E.

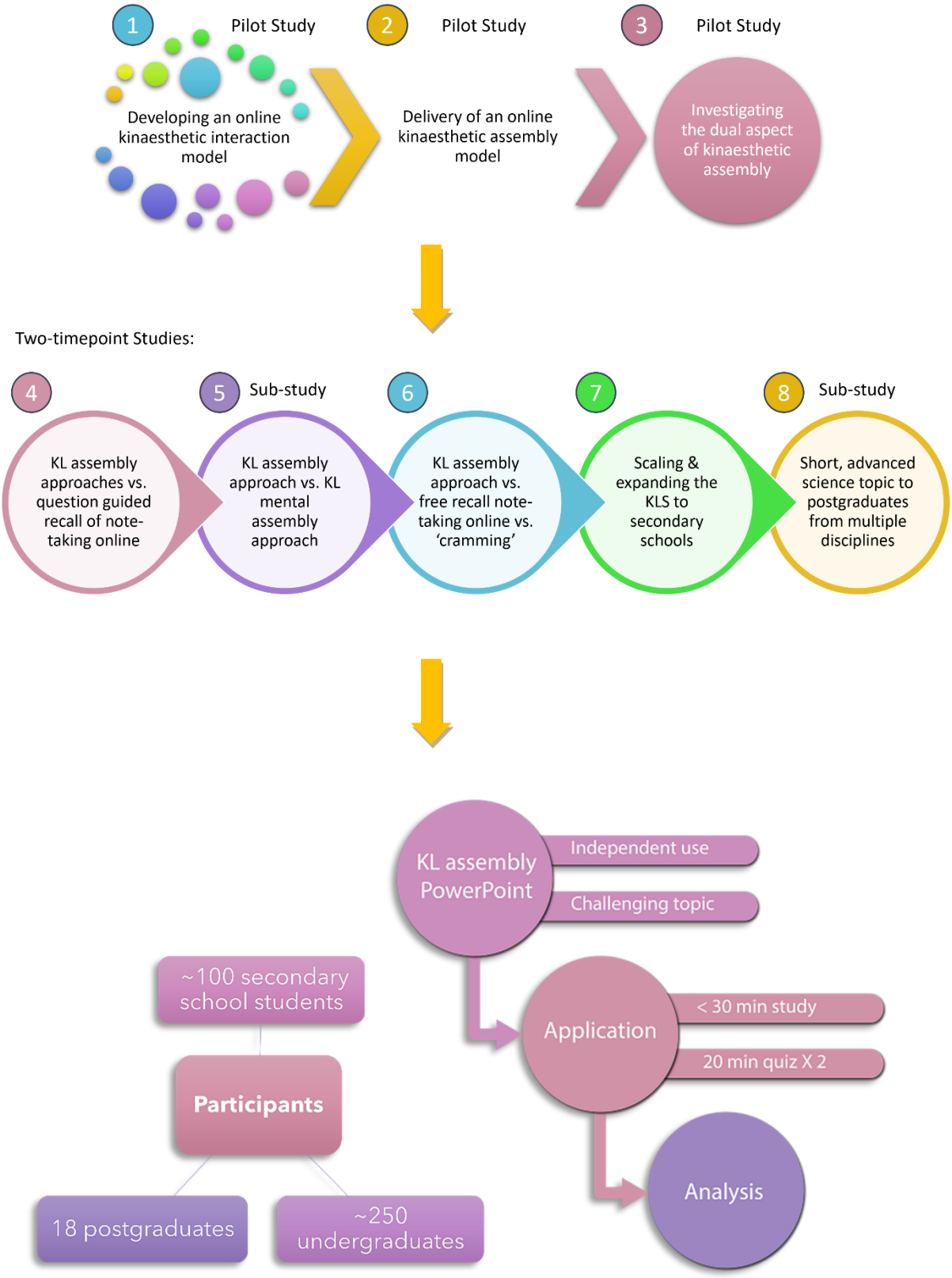


Figure 4.1 Experiment and Methodology Flowcharts. The flow of the overall project is represented, through the initial pilot studies and two-timepoint experiments to the methodological set-up.

CHAPTER 5

PILOT STUDIES

5.1 Introduction

This chapter presents the results of three initial exploratory pilot studies conducted during a single study session. Student feedback informed the ongoing development of the KLS and a thematic content analysis was applied to student feedback retrospectively to provide a more in-depth, unbiased overview of user experience on the KL lessons.

Experiment 1

5.2 Pilot Study toward developing an effective online kinaesthetic interaction model for science learning

5.2.1 Experiment 1 Study Objectives

I. *To give students an understanding of positive and negative gene regulation using the Lac Operon as a paradigm for human gene regulation.*
II. *To give students an appreciation for the advantage that gene regulation confers to an organism.*
III. *To ensure students can recall the different biomolecules and connect the temporal order of their roles to regulation of the Lac Operon.*
IV. *To construct new knowledge by predicting the outcome that hypothetical mutations will have on the Lac Operon.*
V. *Observe whether an online kinaesthetic interaction with lesson diagrams is user friendly and an aid to learning.*
VI. *Gather effective feedback to inform the next stage of KL lesson design.*

Table 5.1 Check for Constructive Alignment of Lac Operon Lesson Experiment 1

	Learning Outcome	Teaching & Learning Activities	Assessment
1)	Categorise & order the structural components of the Lac Operon.	Synchronous self-directed learning. PowerPoint lesson & study tasks.	Paper-based MCQ completed post-study. Includes recall questions and questions involving transfer of knowledge and understanding to new scenarios.
2)	Connect the function of regulatory molecules with their binding sites & temporal order, in response to sugar type.	As above.	MCQ as above.
3)	Relate changes in the presence of glucose & lactose to positive & negative regulation.	As above.	MCQ as above.
4)	Predict the outcome for regulation & function of the Lac Operon given a number of novel hypothetical scenarios.	As above.	Transfer questions in MCQ will assess whether learning can be applied to novel, hypothetical scenarios.
5)	Complete all aspects of the study as directed by researcher & in compliance with study parameters & ethical standards.	Student completion of Participant Questionnaire & Consent Form. Participation in study & MCQ.	Return of Participant Questionnaire & Consent form. Observation of student conduct in class. Completion of study & MCQ as directed.
6)	Provide insight & guidance on the design, delivery & assessment of the KL lesson & quiz.	Student to relate feedback verbally and/or via email.	Communicate with student in response to feedback & evaluate toward improving KLS.
7 (a)	**KLS test:** Employ an onscreen interaction study approach to learn & recap lesson notes & diagrams.	Interact with onscreen assembled diagram scenarios to guide concept development.	MCQ. Invite verbal feedback post-study on student experience. Follow-up with email for written feedback.
7 (b)	**Control:** Employ traditional methods of study, e.g., writing paper-based notes, to learn & recap lesson notes and diagrams.	Student choice to take notes, highlight, create mind maps, etc. to guide concept development.	MCQ. Invite verbal feedback post-study on student experience. Follow-up with email for written feedback.

5.2.2 Stages of Research and Design

Following an extensive review of the literature, design and development of the KL PowerPoint and MCQ, it was time to test the operational aspects and delivery of the online KL lesson and MCQ in a realistic setting. An operations flow chart was created early in the process to manage steps of communication and student recruitment (Figure 5.1).

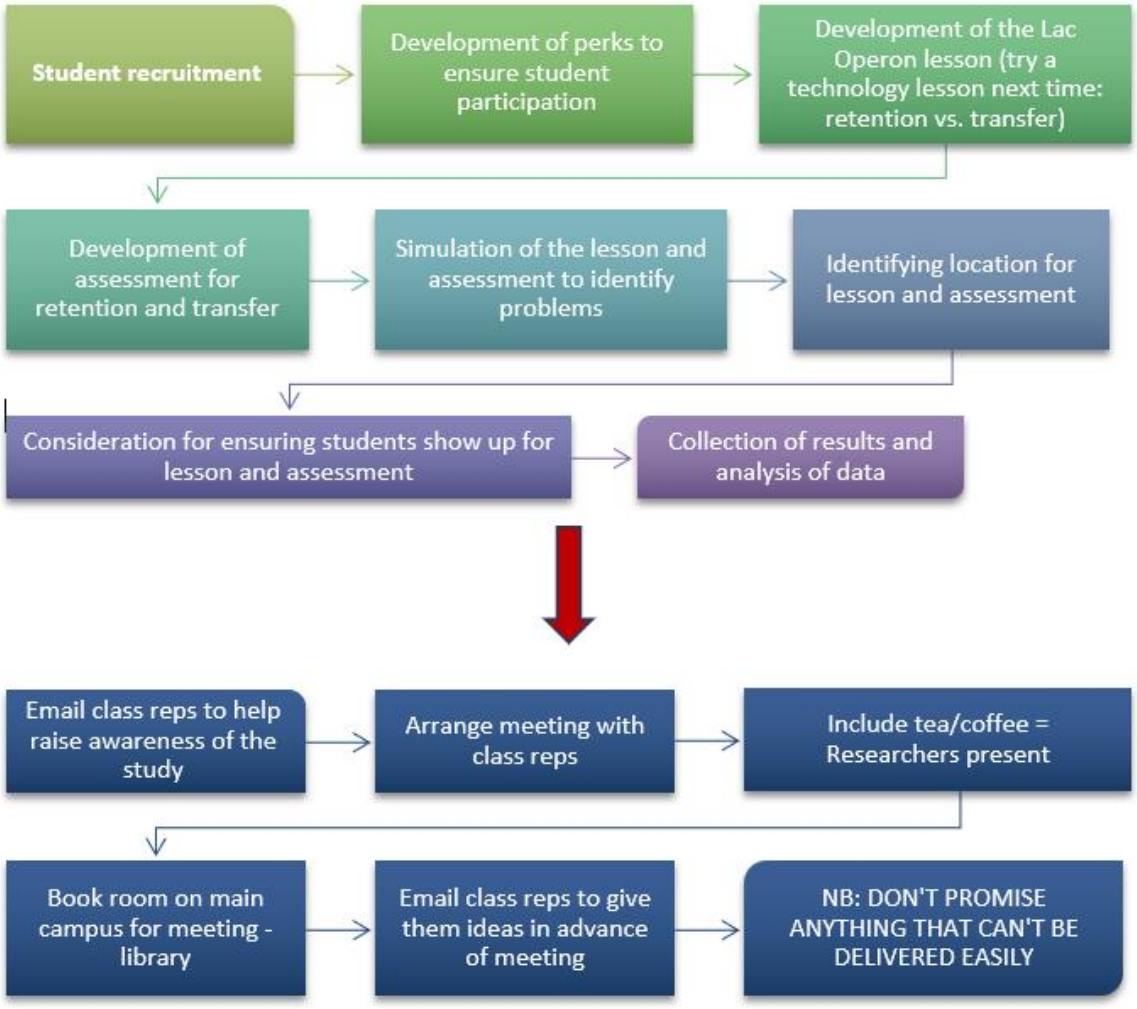


Figure 5.1 Operation Flowchart for Student Communication and Recruitment. The process and logistical considerations for communicating the study to students and organising recruitment are outlined.

In 2019, the researchers created the SCIOPTLE Research Club. The original tagline was 'Science Optimised in Learning' and this was later altered to become 'Optimising Learning in Science'. A dedicated research email was set up to manage any communications between researchers and volunteers, with the approval of the SREC. A shared SCIOPTLE Google Drive account was set up for better collaboration to manage documents and for joint, live writing and editing. The rationale for setting up the club was to incentivise student participation by providing a resource for volunteers to access bonus lectures giving general tips for learning and techniques to improve exam performance. Once a student volunteered for the study, they would automatically be added to the SCIOPTLE Club and would be entitled to attend the bonus lectures, regardless of whether they subsequently withdrew from the

study. The bonus lectures were given by a lecturer involved in this research. This method of recruitment was used consistently for all subsequent KLS experiments except where specified. Appendix A of this thesis includes email communication to students regarding the KLS study and Scioptle bonus lectures.

Students from the 1st year undergraduate medicine subject pool at University College Cork (UCC) were the chosen cohort as the Lac Operon gene regulation system in in *Escherichia coli (E. coli)* is required learning further on in their course. This follows the *beneficence* principle proposed by the American Psychological Association's (APA) *Ethical Principles and Code of Conduct* (2002). One of the researchers lectures this cohort and was willing to set aside lecture time to facilitate the study in a lecture room on campus. Science students also take this topic, but it was not possible to secure their availability at this time. As per the ethical statement submitted for this study, recruitment was not to be biased against gender, race, nationality or learning disability but the aim was to have an equal ratio of males to females, as males are greatly under-represented in much of the current research on e-learning (Slater et al., 2007). This was communicated to students during recruitment. Students were recruited via invitational email and provided information on the study through lecture address and electronically.

Cohen et al., (2007) advise a certain approach toward seeking informed consent and recruiting participants for a research study which was applied from the outset across all experiments and incorporated into Participant Information Questionnaire and Consent forms. This includes having the researchers identify themselves and their background; fully explaining the reason for the research and procedures involved; any ethical consequences from the viewpoint of participants and/or institutions; outlining the research design, how it will be conducted and how results will be reported; informing participants of the option to remove themselves and their data from the study at any stage, regardless of consent give; providing feedback to participants if requested and importantly, protecting the interests, privacy and dignity of participants at all stages.

Consent forms and Participant Information Questionnaires were submitted via Google Forms, copies of which can be viewed in Appendix A, (Figure A.5). Students were asked to communicate using their student email addresses only. They were advised that their email addresses would be replaced with a unique, individual code in Excel for anonymous recording of results from the multiple-choice question

(MCQ) quiz. Students were informed that only the group means would be compared, not individual grades. Twenty-seven students signed up to participate in a KLS pilot study. One student failed to participate on the day. Thirteen participants were randomly assigned to the KLS test group and 13 to the control group. The average age of participants was 20.74 years, of which 10 identified as male and 16 as female.

5.2.3 Procedure

The experiment was conducted on campus in a lecture room that students were familiar with in line with testing in a realistic setting (Torgerson, 2001; Clark & Mayer, 2008; Sankey et al., 2011). Both groups received an identical KLS PowerPoint at the beginning of the study session, with lesson notes presented on the left and relevant pictorial illustrations on the right (see Figure 5.2). Pictures in the PowerPoint for the KLS Test condition could be pulled apart and reassembled, whilst pictures in the control PowerPoint were locked onscreen. Immediately prior to the start of the study session, students were given a brief demonstration on the whiteboard showing how to click and drag various shapes (a triangle, circle and square). The control group was verbally instructed that they were free to make notes as they usually would in a lecture and were provided with paper to do so. These were returned to the researchers after the study session.

Five students had indicated in the Participant Information form that English was not their first language. Therefore, students were told to raise their hand if they did not understand any words in the lesson and this was availed of by one student who asked for some technical words to be clarified to aid her understanding. Students were advised not to communicate with others during the study.

It was observed that a small number of the students in the KLS test group were not interacting fully with the lesson elements despite being verbally instructed to do so at the beginning of the lesson. Following the 25-minute study session, a 3-minute break was given to students prior to commencing the MCQ as per usual procedure in the lecturer's biochemistry class. Students were then issued with an MCQ in paper format which originally had 20 questions for completion.

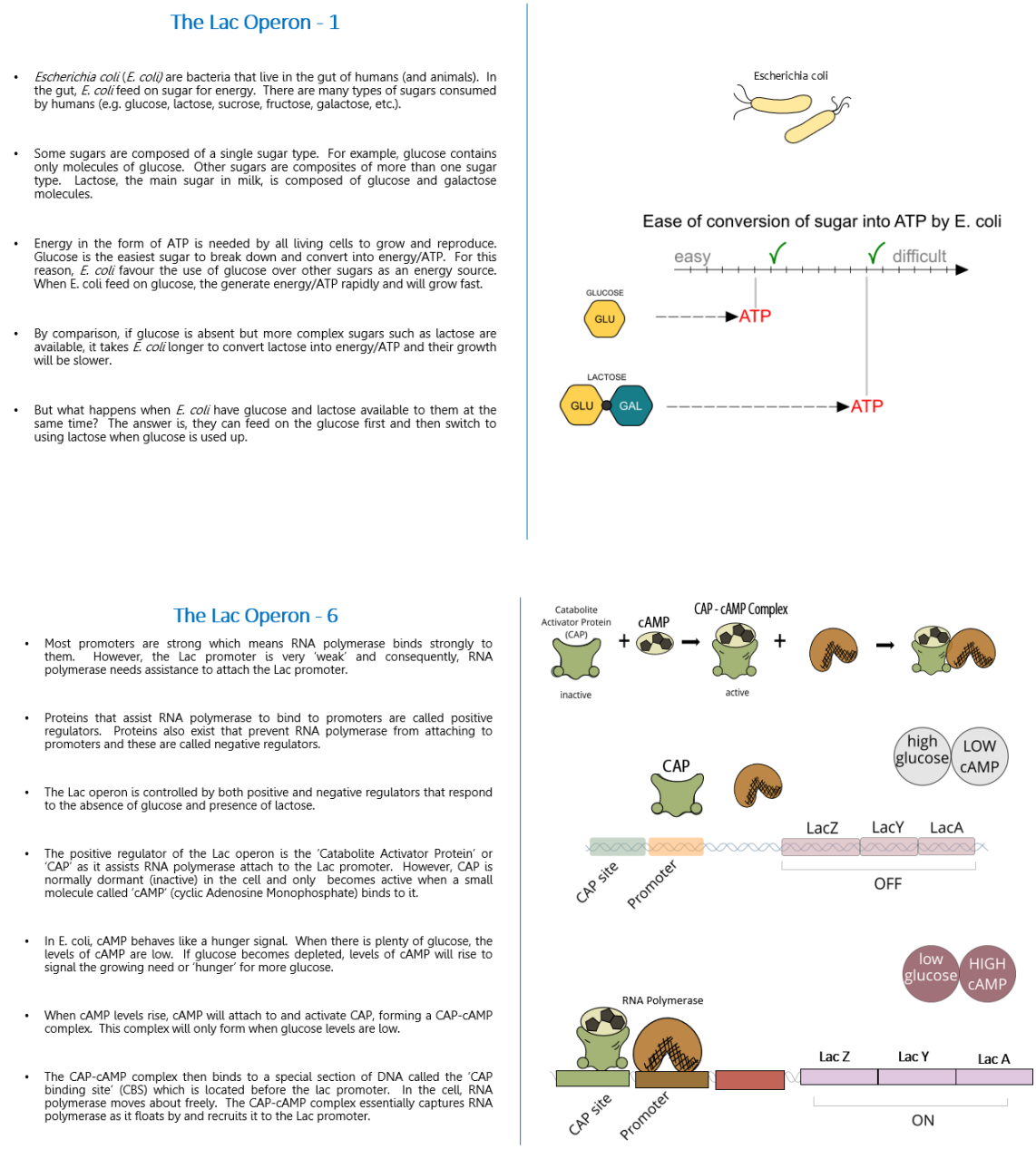


Figure 5.2 Sample of Two KL Lesson Slides from Pilot Study 1. Both study groups received identical lesson slides. Pictures in the KLS test condition could be pulled apart and reassembled whereas pictures remained locked onscreen for the control condition.

The MCQ was reviewed and on further consideration, five of the questions (Qs 4, 8, 12, 16, 19) were removed from the final MCQ as they were deemed too ambiguous by one of the researchers. As the MCQ was already printed, students were advised to cross off the excluded questions. Students spent 20 mins completing the MCQ and these were collected in place by the researchers as per typical exam procedure in

UCC. Correct answers were given a mark of one and incorrect, a mark of zero. Questions 1-18 of the quiz related to the recall of lesson details requiring the student to circle the correct answer from a selection of incorrect answers provided, for example:

6. Which of the following molecules acts like a hunger signal for the Lac operon when glucose decreases?

a) Lactose
b) Cyclic-adenosine monophosphate (cAMP)
c) The Lac operator
d) Lac repressor
e) Trans-acetylase

The correct answer is (b)

Question 20 tested for transfer knowledge - the ability to problem solve using recently learned knowledge and understanding when given a hypothetical scenario. Transfer testing is the standard used in education psychology to test for long-term learning and/or deeper comprehension. In the case of the Lac Operon MCQ, this required the student to recall multiple molecular processes and molecules from across the text and connect these concepts to formulate a viable, predictable outcome.

Q.20. If a mutation occurred in the Lac repressor such that it could no longer bind to allolactose, what would be the most likely outcome?

a) Lac protein production would increase
b) It will have no effect as the operon is regulated by other molecules
c) It will have no effect as lactose can still activate the operon
d) Lac protein production would decrease
e) Lactose would bind instead and lift the repressor off DNA

The correct answer is (d)

5.2.4 Methodology of Analysis of Results

The purpose of this pilot study was to check the operational viability of delivering the interactive KL lesson to students from a relevant study cohort and have them complete the steps of the study within the defined study parameters. Although pilot studies are not run for statistical purposes but to inform design for the goal of running a larger study, some quantitative data arose from the MCQ. Because the data was gathered, it was checked to see if there were any observable differences between the KLS test and control groups.

Setting the study up to facilitate qualitative feedback formed a critical component of the KLS design and development. A qualitative analysis is primarily concerned with understanding and explaining how individuals perceive their experiences through an idiographic approach (in this case, individual student feedback) and from an anti-positivist viewpoint (Cohen et al., 2007). A qualitative thematic content analysis is particularly useful for psychology related research when trying to establish something from the opinions or experiences of individuals, from a given set of data (Caulfield, 2022). Because a theme can only reflect a pattern of responses arising from codes, the judgement of the researcher is still necessary to interpret that pattern within the wider context of the data:

> *"the 'keyness' of a theme is not necessarily dependent on quantifiable measures – but rather on whether it captures something important in relation to the overall research question" (Braun & Clarke, 2006).*

However, this approach can introduce bias if not done transparently. To control for bias yet still enable the researcher's necessary subjectivity, Braun and Clarke's six-step guide for conducting a simple thematic analysis was applied:

1) Familiarise yourself with the data by re-reading several times and taking notes.
2) Generate initial codes in a systematic way and collate relevant data to each code.
3) Search for themes by matching and collating relevant data into subcategories.
4) Review themes by generating categories from the subcategories to create an overall 'thematic map.'
5) Define and name themes through ongoing analysis.
6) Produce a report using a selection of extracts relating back to the research question.

Verbal feedback was sought from students immediately post quiz. All students (except one) indicated they had enough time to complete the study session, and all agreed they had enough time to complete the MCQ. A small number of students in the KLS test group reported they did not feel the need to interact with all illustrations as they understood the lesson content well enough. Students were thanked for their time immediately after the study session and it was acknowledged that the setup and approach required further work. Students were encouraged to

continue contributing their opinions informally via email and invited to address the following questions:

1. *Anything that you thought was problematic in the learning approach presented?*
2. *Anything that immediately came to your mind that said – this does not make sense?*
3. *What kind of situation would you be enticed to move / rearrange objects on a screen?*
4. *What improvements if any can you suggest?*
5. *Any other intuitive thoughts that you might have on the test / approach – intuitive thoughts are great – they are easy to capture as they are the first thing that comes into your head – so feel free to share the first few thoughts that come into your head about the test approach.*

Individual student feedback was copied and pasted from their email responses into a single Word doc and imported into NVIVO 12 (released March 2020). When a thematic framework is well defined, it should be obvious to any person what the focus of the analysis is about without having to read the original transcript (URL 8). To ensure a well-defined framework, an initial set of codes was generated manually via line-by-line analysis. Sub-categories were created to group similar codes together and a pattern of feedback began to emerge. Sub-categories reflecting closely similar themes were further condensed into relevant categories and finally, the main semantic themes relating back to the purpose of the pilot study were identified as reported in results. This approach was used retrospectively to perform a simple analysis of the qualitative data in this and the subsequent pilot study.

5.2.5 Experiment 1 Results

Results appeared positive for an onscreen interaction within PowerPoint, with the KLS Test group (*n* 13, *M* = 91%, *SD* = 9.3) returning a higher mean grade than the Control group (*n* 13, *M* = 78%, *SD* = 22.8) (see Figure 5.3).

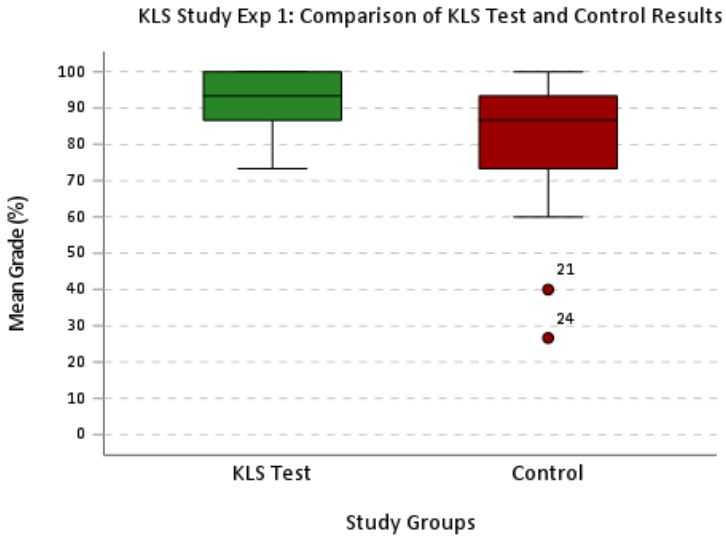


Figure 5.3 Comparison of Mean Grade for the KLS Test Condition vs. Control. Results were positive for an onscreen interaction withing PowerPoint, KLS Test (M = 91%) vs. Control (M = 78%)

Qualitative data underwent a thematic content analysis as outlined in section 5.2.4 and identified three main themes (positive, problematic and improvements) relating back to the focus of the study, i.e., developing an effective online kinaesthetic interaction model (see Figure 5.4). Some students provided very positive feedback on their overall experience of studying the KL PowerPoint lesson and MCQ:

Sample Student Extract (Ext):

34621*: The text and diagrams were clear and well simplified. I liked that not much pre-existing knowledge was assumed and that the difficulty increased gradually as I went through the lecture.*

2926: *I think moving objects would be beneficial in understanding positioning (e.g., muscles in anatomy) and processes like osmosis.*

9545: *The summary slide was really helpful in understanding what the end goal was. I think I learned a lot and I was able to make a good attempt at the MCQ but I don't know how well I retained the information after the fact.*

On the other hand, some students encountered problems in understanding the expectations for the test group and the timing of the study:

Ext:

9545: *There was probably too much text on each slide to have a chance to get through everything.*

2926*: I think less time is probably required to study the quantity of content in the lecture as I found the excess time reduced my desire to focus on the task and, later, the MCQ.*

5751: *In order to get students to move things on the screen there needs to be something to entice them to move those things, e.g., something more interactive like having to put diagrams in a specific order or something.*

34621: *I may have found it easier to interact (with icons) if they were along the top of the screen where I could move them into position as I read through the text.*

4783: *I personally would not move the objects on the screen ..perhaps an alternative would be if they were at the bottom of the page and you had to arrange them into order yourself- would probably feel more beneficial.*

Some very good suggestions for improvements in the areas of engagement and interaction were made by students:

Ext:

4783*: Videos and animation are a brilliant resource when it comes to learning.*

3476*: For moving the objects in the diagram, a simple animation that requires the student to bring the object to its correct position could be an option.*

9545*: If you had the basic elements on the side and then asked to build the final product based on what is in the text.*

2926: *It might also help to make it more clear to the test group that moving the objects is encouraged as I didn't fully understand what was expected until the end.*

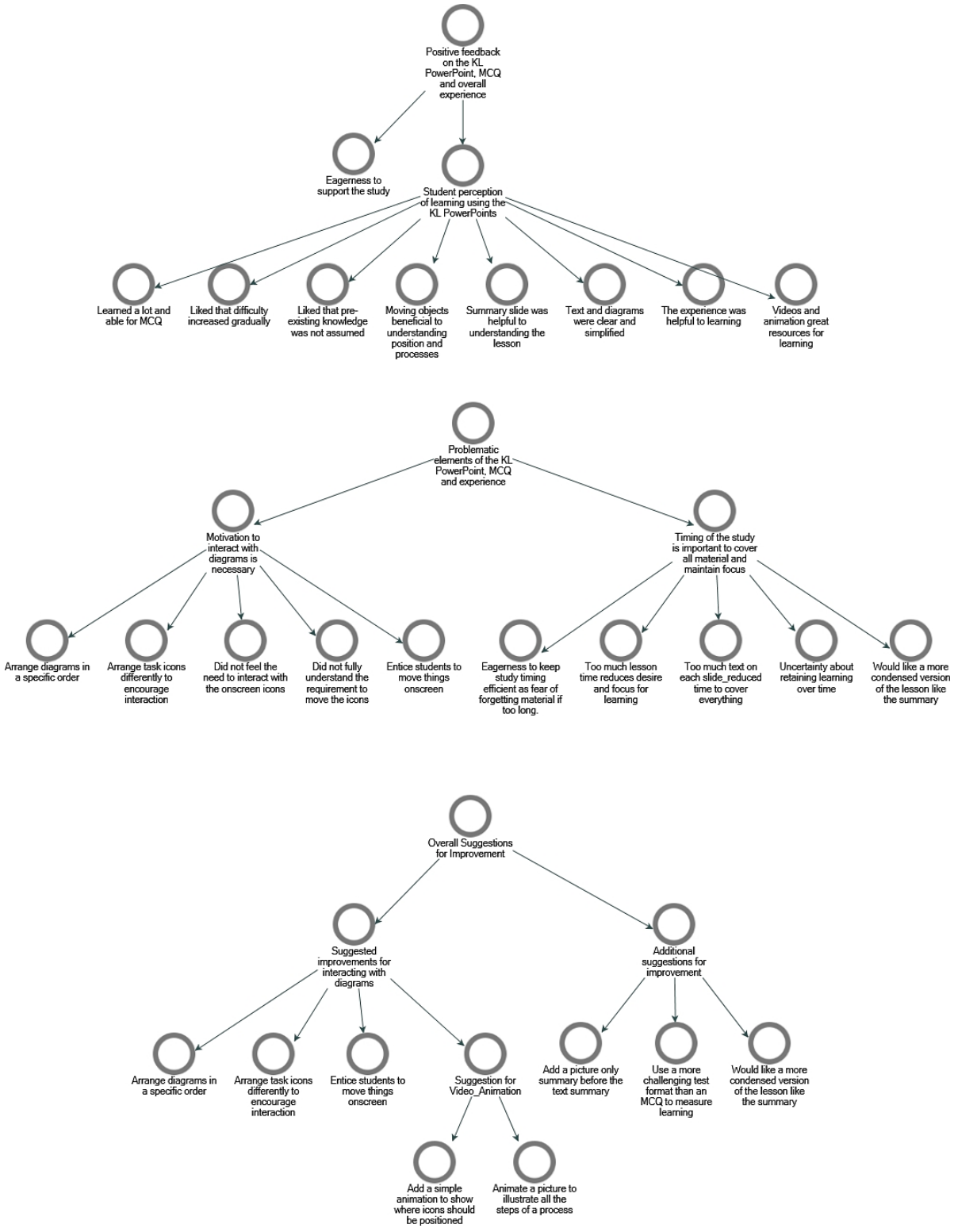


Figure 5.4 Thematic Framework for Experiment 1. Three main themes were identified from student feedback in NVIVO – 'positive', 'problematic' and 'improvements.'

5.2.6 Experiment 1 Discussion

Implementation of the KLS proved possible in a typical undergraduate lecture and assessment scenario, for synchronous delivery and self-directed use. All students completed the study and MCQ within 50 mins and inside the usual lecture time of one hour. Constructive alignment of learning outcomes, teaching and learning activities, and assessment ensured the objectives and learning outcomes were achieved and this was demonstrated by the positive grades earned by both groups for what was a challenging lesson and MCQ. Suggestions for improvement related mainly to slide layout and improving incentive to interact with diagrams, rather than to how the lesson was written or how the concepts were introduced. This validates the lesson text and illustration as being suitably presented, despite the lack of background knowledge for the student. This also proved at the earliest stage that the KLS has both ecological and content validity, much more so it could be argued, than many science lessons used in science/educational psychology research as discussed in Chapter 3, section 3.3.2.

As noted by other researchers, the time required to develop comprehension aids can be prohibitive (Gegner et al., 2009). This was one of the limitations of the KLS in that the conceptualisation and iterative production of the pictorial elements, was particularly time-consuming and required a level of skill to create digitally in Adobe illustrator. Building the biomolecular scenarios and judging what to include/exclude also required considerable discussion amongst subject matter experts, trial and error. Once the repository of icons was agreed upon, the time to production of biomolecular scenarios was rapidly reduced and the flexibility for re-using icons to explore a wide variety of hypothetical scenarios presented an obvious advantage.

Mapping the layout for the KL lesson and online KL approach to best e-learning instructional guidelines (Clark & Mayer, 2008) required significant study of interdisciplinary research in educational psychology and neuroscience. This is not always possible depending on the time constraints of a study or due to a lack of collaborators and this appears to be an ongoing issue in science education research (Dommett et al., 2011). Richard E. Clark and Richard E. Mayer have both produced research toward generating e-learning guidelines in the field of education psychology. Mayer tends to have favoured the exploration of media in influencing learning outcomes (Ruth Clark and Mayer, 2008) whereas Clark took the position

early in his career that it is the methods employed, not the media, which influence learning outcomes (Clark, 1994). Given that the KL PowerPoint was identical for both the KLS Test and Control groups (save for the icons being locked onscreen for the latter), this study appears to uphold Clark's position that learning is affected by method, not media.

One criticism from research is that educators have become focused on test preparation rather than instruction, leading to the:

> *"Unethical practice…where different groups of students are prepared differentially for tests, i.e., giving some students an unfair advantage over others" (Cohen et al., 2007 pg. 433).*

To overcome this, "*teachers should not teach directly to the test*" (Cohen et al., 2007 pg. 433) and the objective should only be to improve instruction instead of test preparation. The use of transfer testing is especially suited to exploring whether a lesson has been understood as it challenges the student to apply what they have learned toward problem solving a hypothetical scenario not encountered in their learning. Because it requires the construction of new knowledge, it can help to circumvent the phenomenon of teaching to a test. Thus, the focus of the MCQ remained as stated to participants, i.e., to measure learning when a particular approach is used. There were just two transfer questions in this MCQ due to the elimination of several questions but also, the purpose was to measure general recall.

The value of digital technology is recognised not only in terms of creating technologically rich environments (TREs) for more holistic, innovative learning and assessment approaches but for accommodating timely feedback from which to plan, revise and modify strategies in collaboration with others (Cohen et al., 2007; Shute et al., 2016; Gamage & Perera, 2021). Student feedback proved pivotal in optimising the layout of the KLS PowerPoints and included spreading the text across more slides and increasing the number of illustrations accordingly. In addition, an animated video showing the flow of biomolecular processes was produced and this served to demonstrate better, the function of key molecules in regulating those processes.

Task slides were introduced following the lesson slides, resulting in more space for the interactive elements in the lesson. This aimed to facilitate a better formative self-check mechanism whereby the student could attempt the task based

on their learning, then re-check their learning by referring to the previous ‘expert’ lesson slide. Icons were positioned at the top or side of PowerPoint task slides to incorporate a ‘puzzle-like’ challenge, whereby students would have to assemble elements into a blank space or over a neutral picture. Explicit instructions were included at the beginning of the PowerPoint to outline the order, timing and navigation of the lesson for each group so that students would understand what was required of them from the outset.

Experiment 2

5.3 Pilot Study on delivery of an online kinaesthetic assembly model

5.3.1 Experiment 2 Study Objectives

I. *Evaluate alterations made to the KLS lesson design and layout following student feedback from Pilot Study 1.*
II. *Test the practicality of delivering KLS lessons in an entirely online format for remote learning off-campus and on students own digital devices.*
III. *Explore whether verbal communication of instructions via animated video format in PowerPoint is better than written instructions.*
IV. *Appraise the value of adding an animated video lesson on the Lac Operon.*
V. *Gather effective feedback to inform the next stage of KL lesson design.*

Table 5.2 Check for Constructive Alignment of Lac Operon Lesson Experiment 2

	Learning Outcome	Teaching & Learning Activities	Assessment
1)	Categorise & order the structural components of the Lac Operon.	Synchronous self-directed learning. PowerPoint lesson & study tasks.	Online MCQ completed post-study. Includes recall questions and questions involving transfer of knowledge and understanding to new scenarios.
2)	Connect the function of regulatory molecules with their binding sites & temporal order, in response to sugar type.	As above.	MCQ as above.
3)	Relate changes in the presence of glucose & lactose to positive & negative regulation.	As above.	MCQ as above.
4)	Predict the outcome for regulation & function of the Lac Operon given a number of novel hypothetical scenarios.	As above.	Transfer questions in MCQ will assess whether learning can be applied to novel, hypothetical scenarios.
5)	Complete all aspects of the study as directed by researcher & in compliance with study parameters & ethical standards.	Student completion of Participant Questionnaire & Consent Form. Participation in study & MCQ.	Return of Participant Questionnaire & Consent form. Completion of study & MCQ as directed.
6)	Provide insight & guidance on the design, delivery & assessment of the KL lesson & quiz.	Student to relate feedback verbally and/or via email.	Communicate with student in response to feedback & evaluate toward improving KLS.
7 (a)	**KLS Test Interaction:** Assemble onscreen diagrams to depict multiple biomolecular scenarios.	Assemble biomolecular scenarios to guide concept development.	MCQ. Verbal and written feedback from students on experience.
7 (b)	**Control Non-Interaction:** Employ traditional methods of study, e.g., writing notes, to learn & recap lesson notes and diagrams.	Student choice to take notes, create mind maps, etc. to guide concept development.	MCQ. Verbal and written feedback from students on experience.

5.3.2 Stages of Research and Design

In February 2020, 65 first-year students from the undergraduate science subject pool at UCC volunteered for the experiment due to run on the 18th of March. The exceptional circumstances of the Covid-19 pandemic forced the closure of all educational institutions in Ireland from the 12th of March 2020. Given the disruption to the normal delivery of education as well as concerns for everyone's health, the date of the experiment was changed to the 18th of May. Although the study was proceeding entirely online and students were free by that time of any educational commitments, moving the dates had a detrimental effect on participation.

Despite maintaining communication regarding the study, only 23 students signed up for the May study session. Efforts to maintain communication included setting up a SCIOPTLE Instagram account in January 2020 as part of the SCIOPTLE Research Club (see Figure 5.5) and this researcher created graphics in an effort to make the account attractive to students. A logo was created and added to the top left of all PowerPoints to associate the PowerPoints more definitively with the research, rather than the students' academic material. The SCIOPTLE Instagram account did not receive much attention from students and was dropped as a communication platform.

A *B* *C*



Figure 5.5 SCIOPTLE Instagram Theme Titles. The above images were illustrated for SCIOPTLE Instagram: (A) Ask the Expert, (B) Phone Distraction, (C) Reaching your Goals.

The experiment proceeded as a pilot study to evaluate the changes made to the KLS PowerPoints on foot of student feedback received from Experiment 1. Eleven students were randomly assigned to the Lac Test Interaction group and 12 to the control. Of these, just 15 students participated on the day, with 5 students remaining in the test group and 10 in the control. The Lac Test Interaction was an adaptation of the previous experiment, with alterations which included adding assembly task slides. Where significant alterations were made to a study condition, the name of the condition was also altered in subsequent experiments to differentiate between the previous prototypes. Groups were approximately equivalent for gender and academic ability, as based on CAO benchmark requirements for entry to the UCC course in 2020 ($\geq$ 510 points). Consent forms and Participant Questionnaires were submitted as per Experiment 1. Student email addresses were replaced with an anonymous code for entry in the multiple-choice question (MCQ) assessment. This was accomplished be sending an email a few days in advance of the study to participating students with the following instructions:

"For all students participating, we are assigning a 4 – digit numeric code to ensure your anonymity going forward as outlined in the Participant Information Sheet. This code is unique to you and we ask that you keep it confidential. Your code for this study is: 1845 (sample). Please keep it close to hand on Monday as you will need to enter it when prompted online. In order to access the study on Monday, we are asking all students to sign in to Google Classroom at 10:50 am to receive brief instructions before the test begins at precisely 11 am. The email you used to communicate with us, is the email address that will be recognised by Google Classroom. Use the Classroom code: ***rqbj6me*** *to join the class."*

The Lac Operon lesson content was presented differently in Experiment 2, with the inclusion of a bespoke Lac Operon video lesson (~15 min) to precede the study of the lesson notes as outlined in Chapter 3, section 3.4.2 (see Figure 5.6).

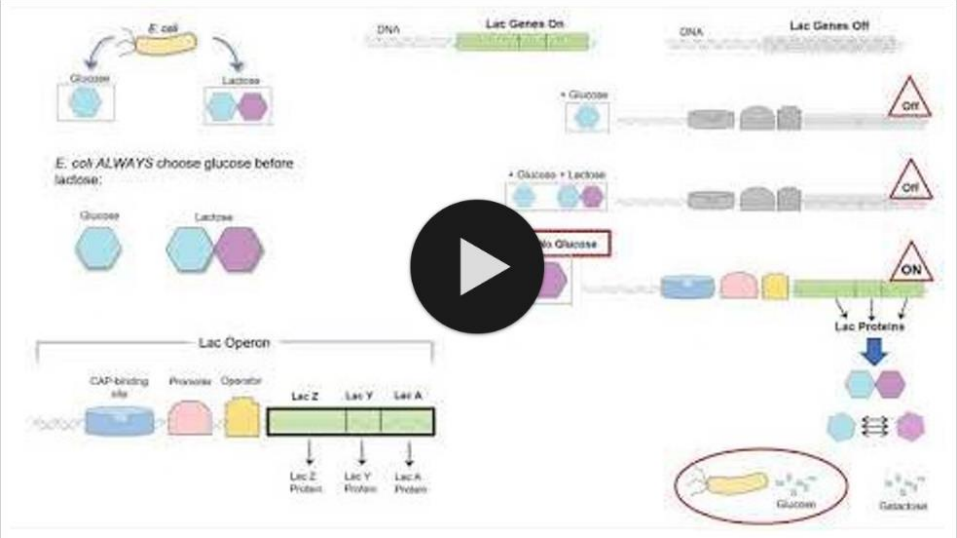


Figure 5.6 Experiment 2 Animated Lac Operon Video Lesson. Link to 15 min original video lesson: https://www.youtube.com/watch?v=e5JJYDfM7g4

It was observed from previous engagement with students that verbal communication appeared to be more effective than written. Therefore, the instructions for Experiment 2 were also animated in stepwise picture and narration format in PowerPoint, with minimal written content used (see Figure 5.7).



Figure 5.7 Experiment 2 Sample Animated Instructions Slide. Link to instructions: https://youtu.be/gc6pft8FVF8

The instructions varied only slightly for the Lac Test Interaction and control groups. A separate slideshow was created presenting the lesson note slides for a period of 10 seconds each. The animated instructions and lesson note slideshow were merged together and converted into a single lesson notes video (see also Chapter 3, Figure 3.3). Students could pause the video for each lesson slide to study the notes and diagrams before pressing play again to move on to the next lesson note slide (Figure 5.8).

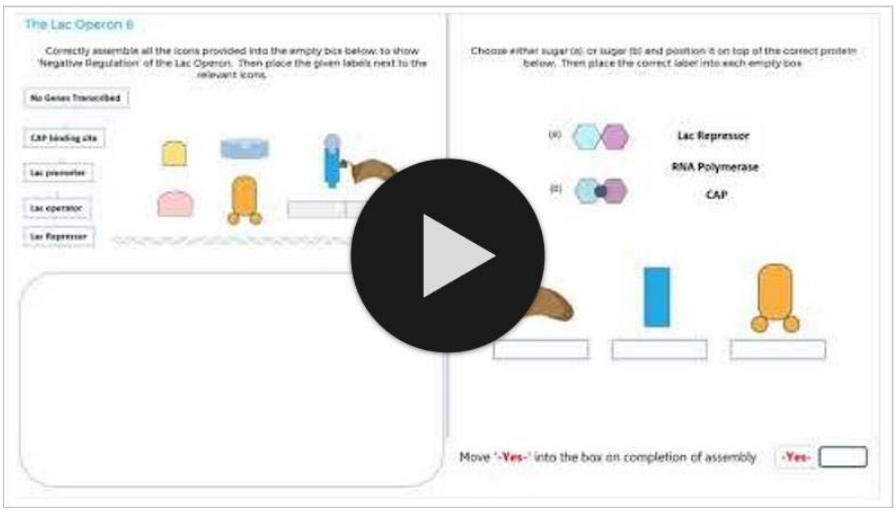


Figure 5.8 Experiment 2 Sample Lesson Notes Slide for Control Group. Link to instructions: https://www.youtube.com/watch?v=_rPNMuvoVZU

The test group had an additional but similar short video on the third slide demonstrating how to interact with onscreen icons.

The test group were given 10 min to study using the lesson notes video and advised to spend approximately 1 min on each slide. Immediately following the third short instructional video, this group had to proceed through and complete a series of 7 task slides. Tasks were designed to become incrementally harder as the student progressed. The first 4 tasks involved the assembly of picture icons over a neutral, whole picture in what effectively was the early prototype of the Guided Assembly condition. The last 3 task slides involved the assembly of a whole picture into a blank slide, and this was the early prototype of the Unguided Assembly condition (conditions outlined in Chapter 3, section 3.5). Students were advised they had approximately 2 min to complete each task slide. Students could refer to the lesson notes during completion of assembly tasks once they had attempted completion of the task to ascertain if they were learning correctly.

The control group did not receive any task slides and their PowerPoint was limited to the two slides containing the embedded videos. Students were given 25 min of study time using the lesson notes video and advised to spend approximately 3 min studying each lesson note slide while using whatever study technique they normally employed.

To summarise, the first slide of each PowerPoint contained the Lac Operon lesson video and the second slide contained the Lesson Notes video which included the instructions relevant to the particular group. The Lac Test Interaction PowerPoint contained a short video on the third slide outlining onscreen interaction, followed by a series of 7 task slides for completion. The control PowerPoint contained just 2 slides in which the videos were embedded. Both groups received 25 min study time which broken down, amounted to ~ 3 min/slide: test (1 min study + 2 min using learning tasks), control (3 min study using usual study method). As both videos were uploaded to the same SCIOPTLE YouTube channel, both could be enabled or disabled by the researcher. This helped to control the study time for both groups to matched exactly by time. It also facilitated live monitoring of YouTube analytics to note the number of views at any one time, confirming to a certain extent the level of student engagement.

5.3.3 Procedure

Students were not based on campus during testing and were free to participate from any location with a strong internet connection. Students were unaware of the topic they would be studying and to which study condition they were assigned in advance. Students were emailed their respective PowerPoints simultaneously at the start of the study session using the blind carbon copy (BCC) function to maintain the anonymity of participants. On completion of the study session, students proceeded immediately to the MCQ accessible in *Google Classrooms.* The MCQ consisted of 25 questions to be completed within a 25-minute period. Questions 1-18 of the quiz related to the recall of lesson details requiring the student to click on the correct answer onscreen, from a selection of answers provided, for example:

Q7. What molecule does the Lac Operon depend on to sense the presence of glucose?

a) Lactose
b) Cyclic-adenosine monophosphate (cAMP)
c) Glucose
d) Catabolite activator protein (CAP)
e) Allolactose

The correct answer is (b)

Questions 19-25 tested for transfer knowledge, for example:

Q20. You are a scientist who has deleted the CAP-binding site from E. coli. Predict the outcome you expect for the Lac operon.

a) There will be strong transcription of the Lac genes in the presence of both lactose and glucose
b) The CAP-cAMP complex will recruit RNA polymerase to bind to DNA and the Lac genes will be transcribed
c) The Lac repressor will remain permanently detached from its binding site leaving the Lac genes free for transcription
d) The Lac genes will be strongly transcribed in the presence of lactose and absence of glucose
e) The CAP-cAMP complex will form but will be unable to bind to DNA and recruit RNA polymerase

The correct answer is (e)

Correct answers were given a mark of 4 and incorrect, a mark of 0.

The quiz results in Google Forms were downloaded and sorted in Excel.

5.3.4 Methodology of Analysis of Results

As per Experiment 1. Similar to the first pilot study, data arising from the MCQ was checked for any observable differences between the Lac Test Interaction and control groups. Student feedback on their experience of the KLS study was gathered via email (Appendix A, Figure A.4) and analysed later using NVIVO. For the Lac Test Interaction group, the task slides included a mix of both guided and unguided formats of assembly. From this, it would be possible to see if assembly could communicate visually whether or not a student was struggling to grasp any lesson concepts. Students in the test group were asked to email their KL PowerPoints back to this researcher to establish the level of engagement in assembly the tasks. This engagement through completion of KL lesson tasks can be visualised from returned PowerPoint slides in Results.

5.3.5 Experiment 2 Results

While the sample size for the pilot study was less than anticipated, it yielded good quality information. As with Experiment 1, the quantitative data gathered from the MCQ quiz was observed for any differences in learning (see Figure 5.9). The Lac Test Interaction group showed a slightly better performance (*n* 5, *M* = 57%, *SD* = 14.8) than the control group (*n* 10, *M* = 53%, *SD* = 23.2) but no generalisations can be made from such a small sample with uneven group sizes.

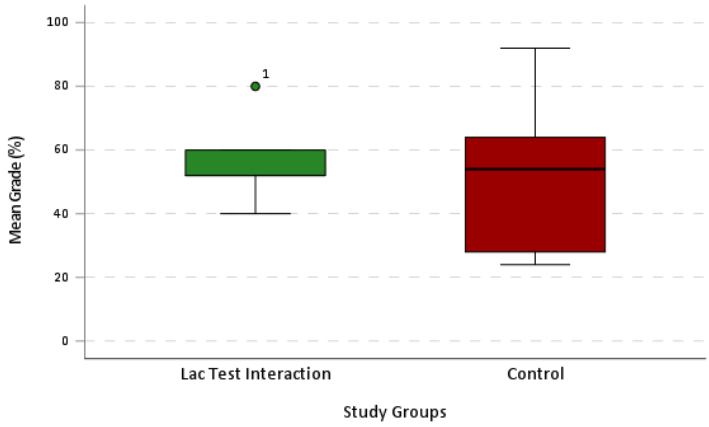


Figure 5.9 Experiment 2 Comparison of mean grade for Lac Test Interaction vs. Control. Results were positive for an onscreen interaction withing PowerPoint, Lac Test Interaction (M = 57%) vs. Control (M = 53%)

Student feedback on their learning experience was reflective of the technical difficulties they encountered with this version of the KL PowerPoint lesson. Although feedback appeared positive overall, a thematic content analysis was conducted in NVIVO for an unbiased identification of themes in relation to student experience (see thematic framework Appendix B, Figure B.1). Students from the Lac Test Interaction group provided positive feedback in relation to understanding the lesson content, interacting with the tasks, the MCQ and lesson video:

Sample Student Extract (Ext)

K *(pre-tested the Lac Test Interaction lesson prior to the main study session. Hence, MCQ results are not included with the main experiment): I found the explanations good, clear and simple to understand; The alphabet explanation for genetic code was great!....I enjoyed this! It wasn't boring and everything was succinct and to the point. The diagrams made it more fun.*

7713: *I liked the interactive slides as they gave us a visual representation of what we were learning about. It's always easier to be able to visualize….The interactive slides were good and a nice yet different way to learn. I think this sort of interactive activity learning is very beneficial. The MCQ incorporated a problem-solving element that will benefit learners and distinguish between those who understand and those who are rote learners.*

1963: *The dragging went well and was easier to understand once I had watched the instructions in the video…Once the videos worked, I thought the audio and structure to them were very well done.*

1845*: It was a very helpful learning technique.*

Positive feedback from the control group was similar:

Ext:

T (pre-tested the Lac Control lesson prior to the main study session. Hence, MCQ results are not included with the main experiment):

(T) The lesson is great, it makes most everything abundantly clear. I wish we had similar available for every topic and subject…Thanks for the context on who these videos are aimed at. I think teaching this material without taking months to teach all the background could be incredibly powerful.

1982: *Technical issues aside, I felt that ample time was given to absorb the lecture content using both the lecture itself and the revision slides; the videos were clear visually and audibly.*

2738: *The audio was very clear…all the content was very clear and easy to read.*

7361: *I felt yesterday I had enough time to learn from the lesson…I was able to see all the content. I used a Mac book and found it went okay!*

The test group identified problematic elements they encountered which were mainly related to not downloading or opening the PowerPoint and embedded videos as directed in the email instructions and this impacted the interactive capabilities:

Ext:

1845: *I had an issue with the last slide of the PowerPoint that the answers are setting behind the green boxes (two students reported this issue).*

9286: *I found it very difficult to understand the PowerPoint and wasn't sure where to find information on the slides to know where to drag each symbol into the correct slot.*

7713: *It (the PowerPoint) was in a protected view and I did not realise I had to disable my own computer's protection to be able to access the videos. This reduced time for study.*

1963: *It wasn't until nearly the end of the lesson that I discovered there were videos at the beginning of the PowerPoint so I didn't have much time to complete it.*

5839: *I tried both ways as in I downloaded it (the PowerPoint) first and then tried to use it straight from the email, neither of which worked…The first 3 slides of the PowerPoint were blurry so I couldn't read them and couldn't interact with it…I won't take the MCQ cause that will mess up your data.*

The control group sounded similar issues:

1982: *I had some trouble accessing the video links via the PowerPoint slides and felt that this method of sharing the videos was somewhat confusing.*

9: *When I opened the PowerPoint, all I saw were two static images (student was subsequently guided on how to access the videos)…had trouble entering the MCQ on Google Classroom even though could see the assignment created.*

Students from both groups provided very constructive suggestions for improvement:

Ext:

9286: *Give information on one slide and the interactive version of the same slide after it.*

K: *Titles/subtitles before each slide would be helpful as it was sometimes confusing when you would start explaining something… I remember from Leaving cert a LOT of people confused translation and transcription so maybe an explanation of the difference or a quick way to remember it would be helpful.*

7713: *Could have done with more time for learning but that is more because I didn't find the videos for quite some time… perhaps increase by 5 minutes.*

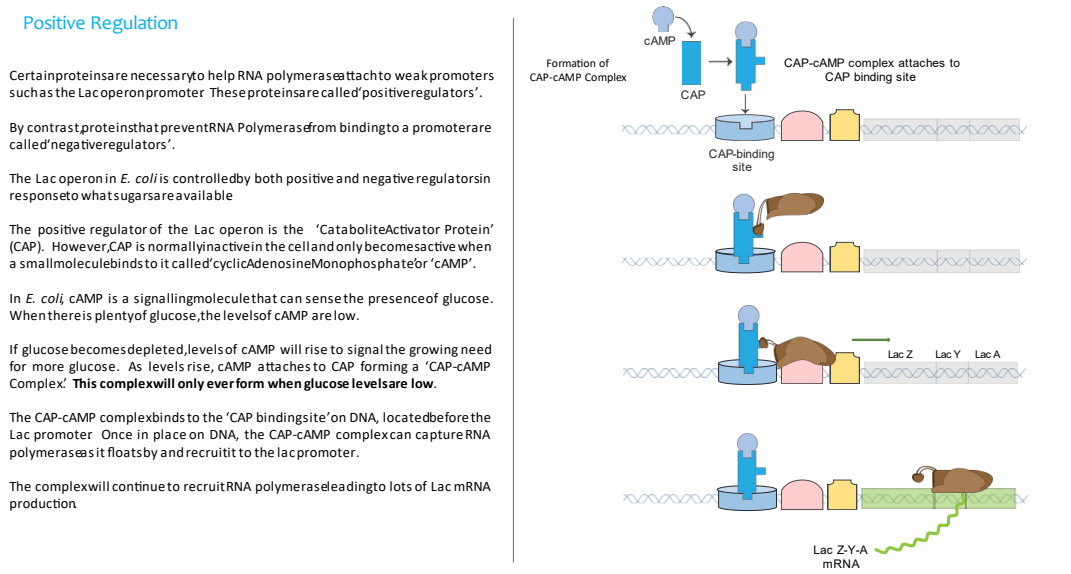
There were less suggestions for improvement from the control group but as this group did not use any interaction and encountered less technical difficulties:

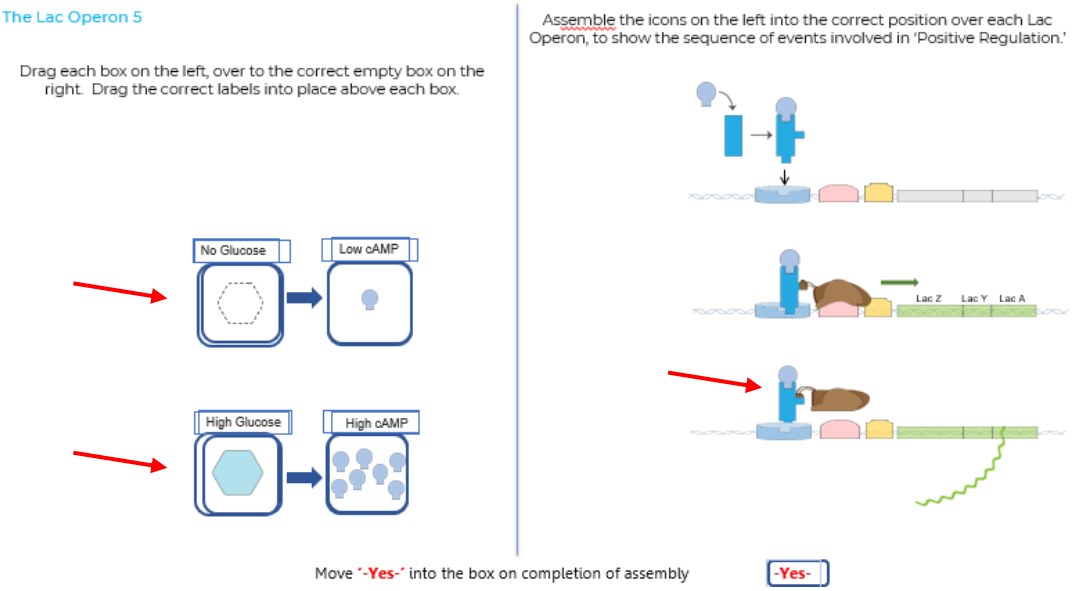
1982: *Attach the video link directly to the email.*

T: *Explain the format at the start of the lecture - a quick slide to say, "welcome to lesson, you're going to watch a 15 min video, then study for a while, then do an MCQ"…Include an outline of what's going to be taught at the start of the lecture.*

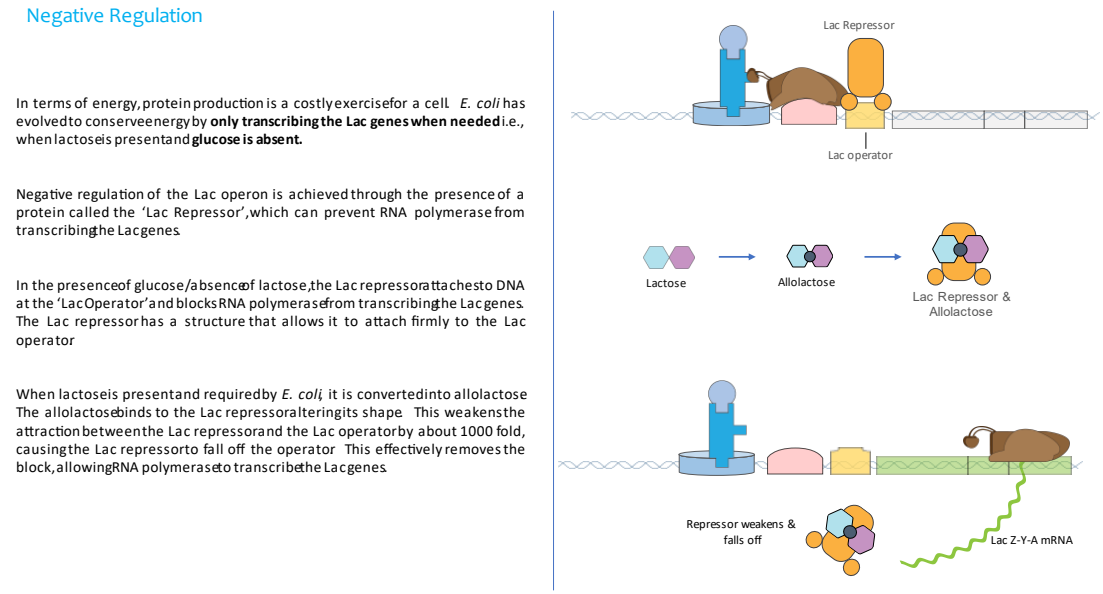
The control group were also asked to identify the study methods they used and the majority reported that they took revision notes.

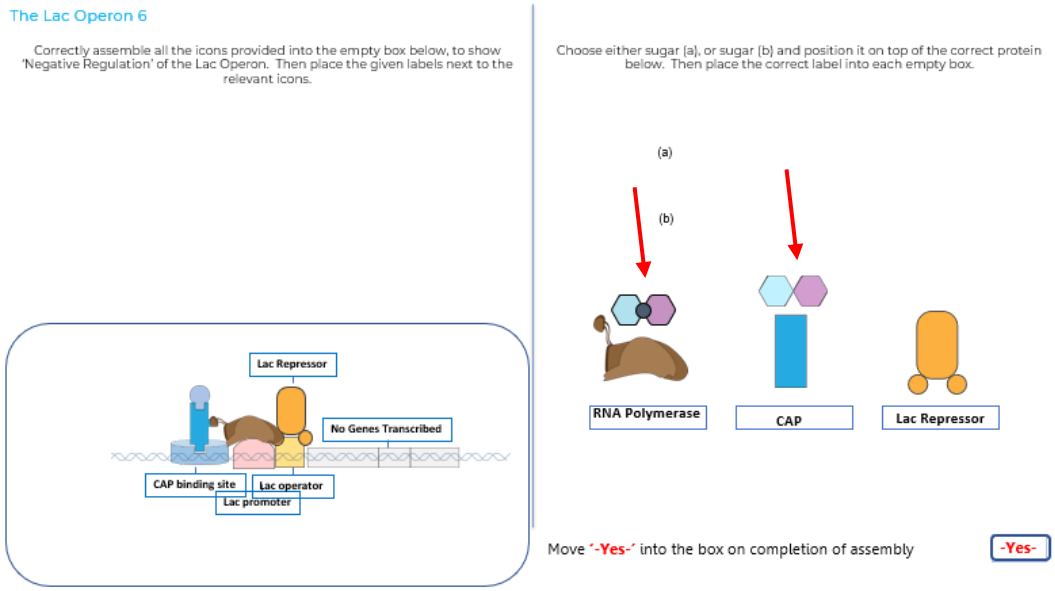
Students in the Lac Test Interaction group were asked to email PowerPoints back to the researchers and Figure 5.10 is an example of how a student completed the PowerPoint. The concepts that this student struggled with can be pinpointed (red arrows for incorrect) through the manner the unguided tasks were completed in slides 5, 6 and 7. Although the lesson slides for this experiment appeared in animated video format only (which could be paused), a sample of the 'expert' lesson slides are displayed above the task slides as a comparison to show how the diagrams should have been assembled. Where sample slides are being presented in this chapter, student study codes have been replaced with 'student 1, student 2, etc.' so as not to identify the performance of the task with the individual.



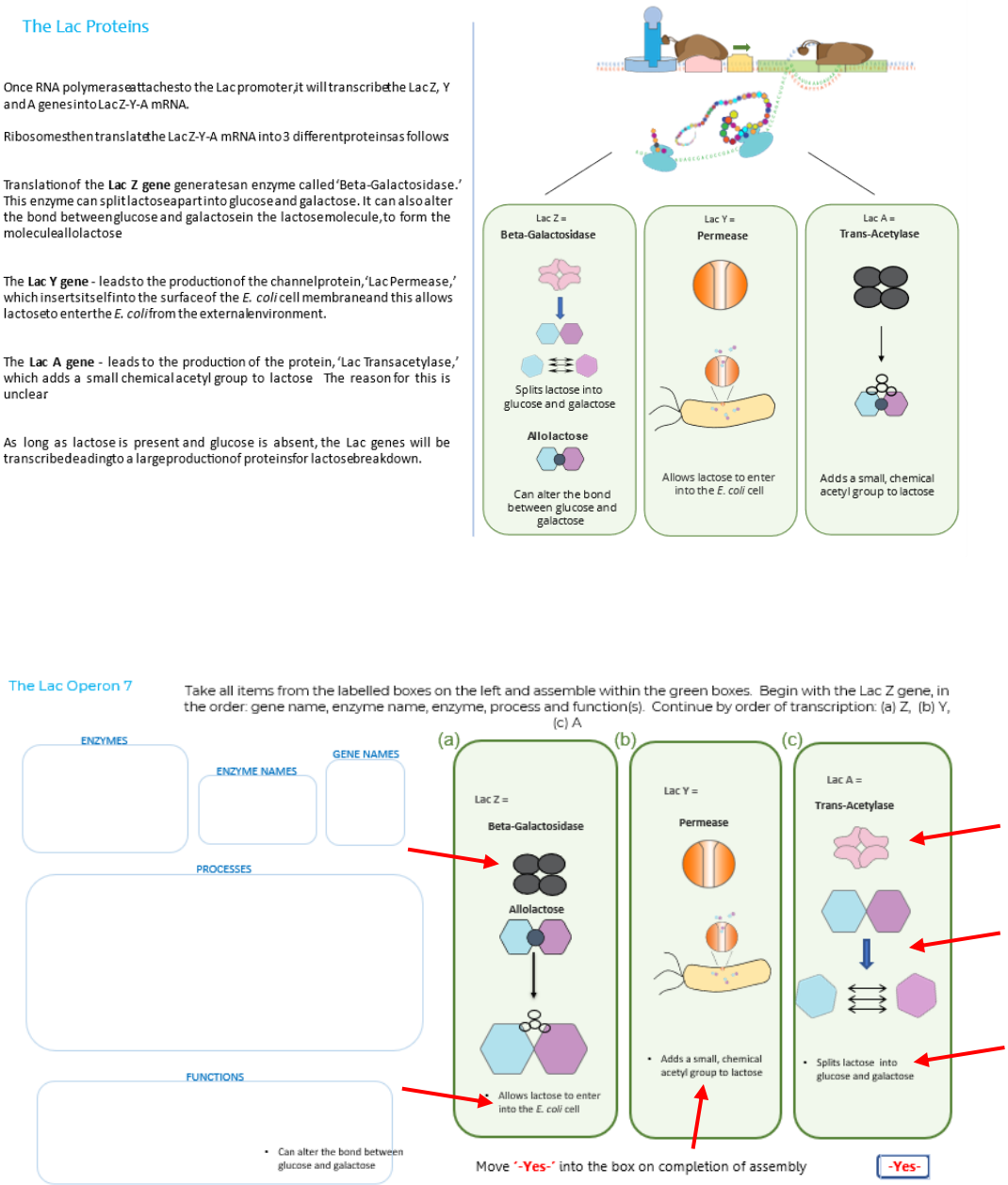


5.10.i. Slide 5 Lesson and Task Slide. On the left, the absence of glucose should lead to high cAMP and high presence of glucose to low cAMP. Students were shown this visual in the video lesson. On the right, the last step of the sequence for transcription required RNA Polymerase to be positioned on the Lac genes above the mRNA strand being transcribed.





5.10.ii. Slide 6 Lesson and Task Slide. Allolactose binds to the Lac Repressor, not to RNA Polymerase and lactose does not bind to the CAP protein.

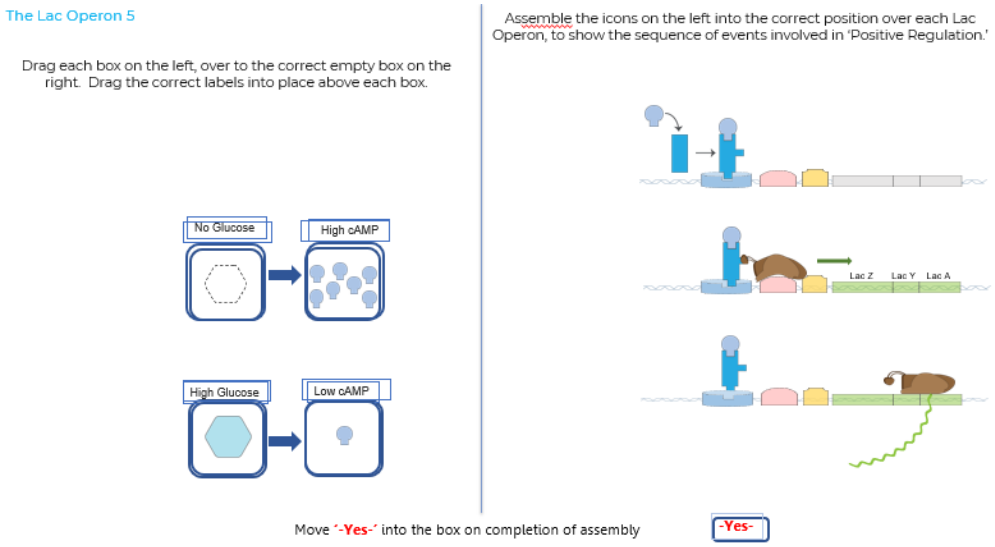


5.10.iii. Slide 7 Lesson and Task Slide. Multiple mistakes are made in the above task.

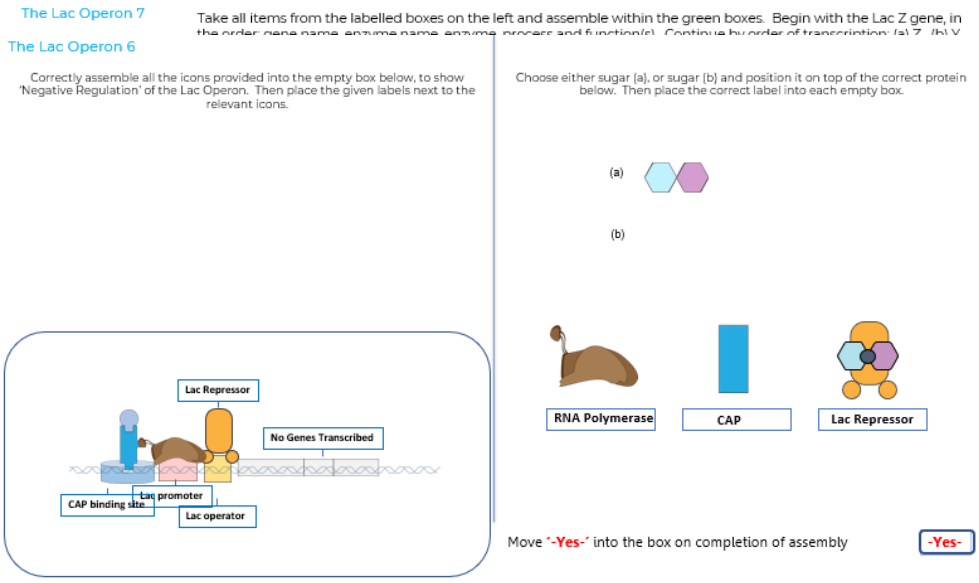
Figure 5.10 Student 1 Unguided Assembly Task Slides 5, 6 & 7 Completed Correctly

Bear in mind, this student cohort had no prior exposure to, or scaffolding for, the multiple concepts outlined in the Lac Operon. Yet, the above student returned a good passing grade (over 50%) for an advanced lecture learned in under 30 min. Two further examples which appear to show the predictability of unguided assembly task completion for learning can be viewed in the following returned PowerPoints

for *Student 2* who returned a grade of 80% in the MCQ (Figure 5.11); and for *Student 3* who returned a grade of 40% (Figure 5.12).



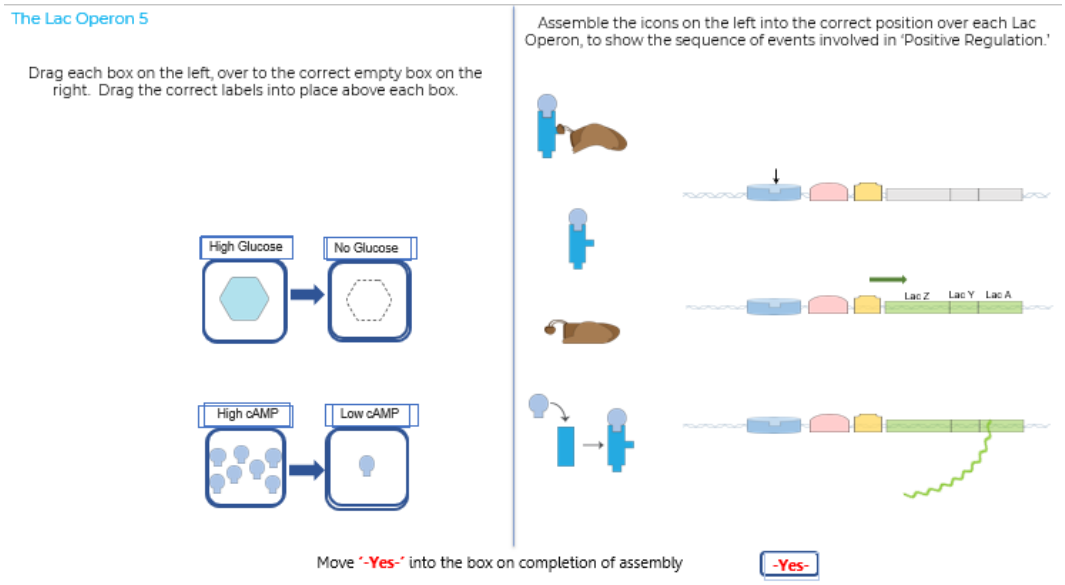
5.11.i. Task Slide 5



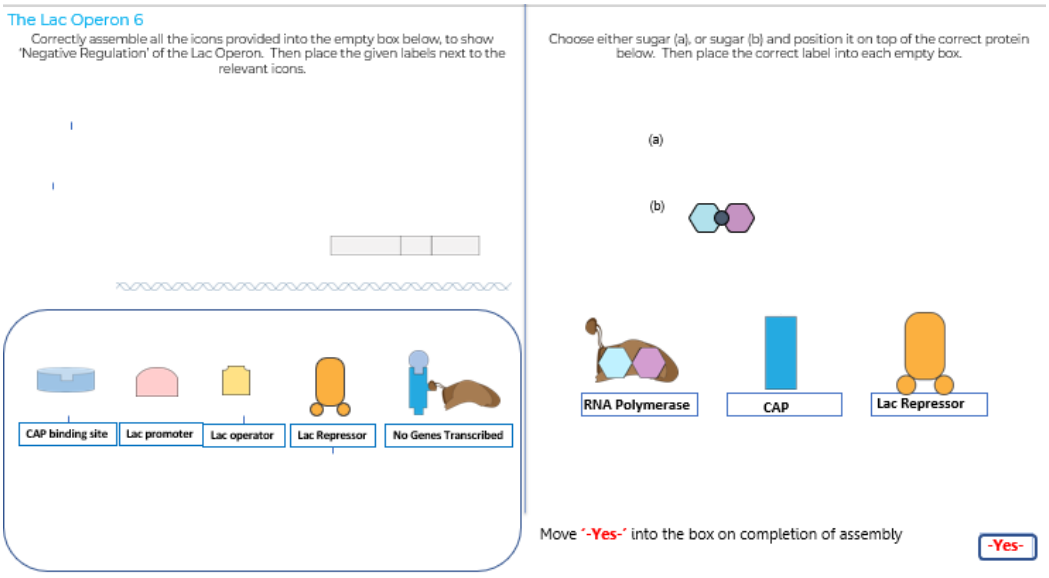
5.11.ii. Task Slide 6

5.11.iii. Task Slide 7

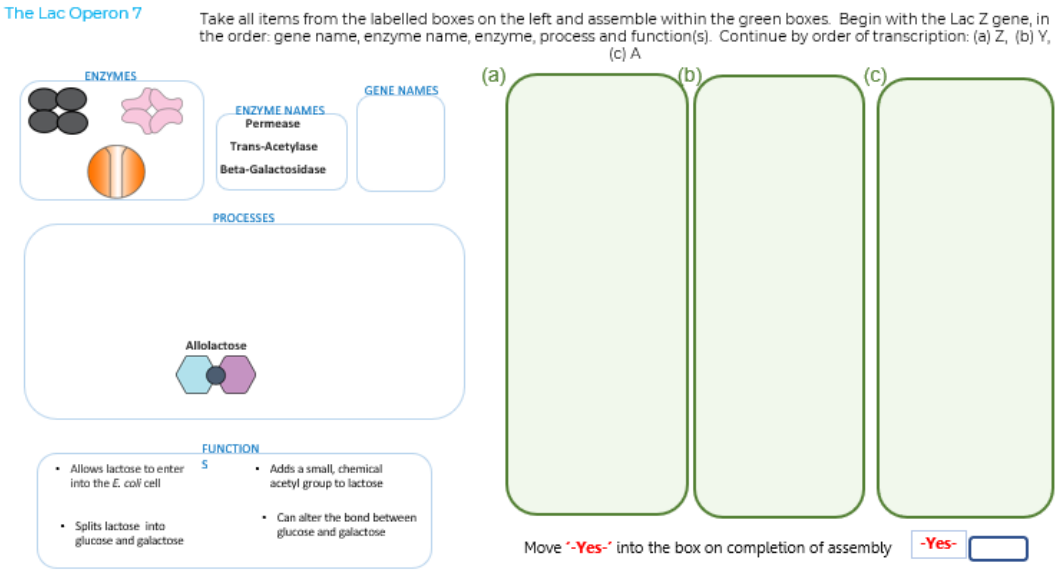
Figure 5.11 Student 2 Unguided Assembly Task Slides 5, 6 and 7 Completed Correctly



5.12.i. Task Slide 5. Incorrect completion of assembly on the left and incomplete task on the right.



5.12.ii. Task Slide 6. Labels correctly identify components, but assembly is incorrect.



5.12.iii. Task Slide 7. In this slide, some students reported that when they tried to place icons into the green boxes (above), they disappeared behind the boxes instead. This appears to be the case in this example, given the missing icons on the left.

Figure 5.12 Student 3 Incomplete & Incorrect Unguided Assembly Task slides 5, 6 & 7

5.3.6 Experiment 2 Discussion

The objectives for Experiment 2 revolved around evaluating alterations made to the KLS lesson format following feedback from the first pilot study. This included delivering the KLS lessons online for remote learning. The latter objective was to better align student learning with how they would study in reality, on their own devices and in a setting of their choosing. This was unexpectedly prescient as the Covid-19 pandemic saw widespread worldwide lockdowns. As the lessons were already set up for remote online delivery, it was expected that students who volunteered would still participate, especially in light of reduced activities and in Ireland, a 5km travel limit from home. The fact that there was such a high dropout (65 students initially which reduced to 23, with a final cohort of 15) may reflect digital technology fatigue but this is purely speculative.

Other studies suggest a detrimental effect to learning when it is a fully online experience. For example, a nationwide study in America analysing almost 60,000 undergraduates from January to June 2021 found that students who attended classes fully online experienced more psychological distress than those who attended in-person or who received a hybrid delivery, regardless of location, school year, gender, race, depression/anxiety, Covid-19 concerns or even whether they were staying with family, off campus or on campus (Van Beusekom, 2022). It may well be that mental health will need to be studied more closely in relation to online learning, to a greater degree than was understood or considered prior to the pandemic.

The PowerPoint format for this experiment was quite different from Experiment 1 in that all instructions and lesson slides were animated. With hindsight, this was an over-ambitious interpretation of student feedback recommending more animation. Consequently, this format actually reduced some of the positive elements identified in Experiment 1, by removing the lesson text and diagrams from slides and presenting in video format only. Animating lesson content can be difficult to accomplish, as pointed out by Fiorella et al., (2017):

"There is a paucity of rigorous empirical research to inform educators and instructional designers on how to design video lessons effectively" (p. 662)

Despite this, the animated video was well received and followed Fiorella's recommendation to present video modelling examples as "*to-be-performed actions from the learner's own perspective*." This was achieved by using the same icons and scenarios from the PowerPoint lesson slides and animating them in the same order of appearance of the lesson slides. Thus, the students were primed to assemble the

tasks, i.e., the *"to-be-performed actions"* in the same way as presented in the video. Although presenting the animation did not fully replicate Fiorella's first-person perspective effect, it did produce the benefit of modelling the assembly for tasks in advance. Fiorella saw potential for applying the perspective effect to STEM subjects in models that could enhance the teaching of:

> *"complex spatial relations of molecules in chemistry, or in the use of concrete manipulatives to teach abstract math concepts" (P. 663).*

The combination of the KLS Lac Operon video lesson with the subsequent assembly of biomolecular tasks achieves Fiorella's objective, as evidenced by the grades and student feedback. The addition of distinct task slides for the Lac Test Interaction group also provided more structure to the assembly slides. The first set of tasks required simple assembly of icons depicting biomolecular scenarios, on top of neutral diagrams. These progressed to a more challenging assembly of scenarios into a blank space, without the aid of guides.

Apart from an overall less optimal layout in terms of the videos, several factors impacted the results of this experiment. Students were instructed to log into Google Classrooms Meet to receive guidance on playing the instructional and lesson videos. When Classrooms would not open for some, students were instructed to switch to MS Teams. This caused some confusion, and a small number of students did not hear all instructions fully. In addition, some students attempted to open the PowerPoint within Gmail instead of downloading it as instructed in the study email. This prevented the videos being played, as well as voiding any possible interaction within the task slides which remain visible but locked unless downloaded. Hence, it transpired that a number of students were late in playing the embedded PowerPoint videos which formed the crux of the lesson. Those who did not hear the instructions were uncertain how to interact with task slides and those who tried to use the PowerPoint as a pop-out window from Gmail could not interact for technical reasons.

Immediately after the study session, students were directed to log into Classrooms to access the MCQ quiz but this also proved problematic for a small number of students even though all were given the same access code. A Word doc. version was emailed to these students who returned their completed MCQ by email within the same timeframe as the rest of the students. However, for all subsequent

experiments, a direct link was provided to a Google Form Quiz and this proved a more successful method of quiz delivery.

Verbal and emailed feedback from students was heeded when re-evaluating the KLS lesson design and delivery. Despite the technical difficulties encountered, the KLS Test Interaction group again returned a higher mean grade than the traditional control group albeit a single outlier may have skewed results in the positive direction (as seen in Figure 5.9). A decision was taken to replace the traditional control in subsequent testing with a model that has proven statistical significance for learning, for a more robust comparison of any KLS test group going forward.

Several students required guidance with basic troubleshooting during the study and apart from access to *Google Classrooms,* the majority of the technical difficulties that arose can be attributed to students not following instructions correctly. This had a knock-on effect for how they encountered the animated instructions, lesson and tasks. Thus, a return to text-based instructions and lesson content was required within the PowerPoint.

Experiment 3

5.4 Pilot Study investigating the dual aspect of kinaesthetic assembly

5.4.1 Experiment 3 Study Objectives

I. *Evaluate alterations made to the KL lesson design, layout and delivery following student feedback from Pilot Study 2.*

II. *Assess whether the KLS is expandable to other disciplines and academic levels, using the same advanced Lac Operon lesson for remote delivery to students regardless of science aptitude.*

III. *Explore whether kinaesthetic assembly requires a recall + movement aspect (KLSA condition) or a movement alone aspect (Guided Assembly condition) for learning.*

Table 5.3 Check for Constructive Alignment of Lac Operon Lesson Experiment 3

	Learning Outcome	Teaching & Learning Activities	Assessment
1)	Categorise & order the structural components of the Lac Operon.	Synchronous self-directed learning. PowerPoint lesson & study tasks.	Online MCQ completed post-study. Includes recall questions and questions involving transfer of knowledge and understanding to new scenarios.
2)	Connect the function of regulatory molecules with their binding sites & temporal order, in response to sugar type.	As above.	MCQ as above.
3)	Relate changes in the presence of glucose & lactose to positive & negative regulation.	As above.	MCQ as above.
4)	Predict the outcome for regulation & function of the Lac Operon given a number of novel hypothetical scenarios.	As above.	Transfer questions in MCQ will assess whether learning can be applied to novel, hypothetical scenarios.
5)	Complete all aspects of the study as directed by researcher & in compliance with study parameters & ethical standards.	Student completion of Participant Questionnaire & Consent Form. Participation in study & MCQ.	Return of Participant Questionnaire & Consent form. Completion of study & MCQ.
6)	Provide insight & guidance on the design, delivery & assessment of the KL lesson & quiz.	Student to relate feedback verbally and/or via email.	Communicate with student in response to feedback & evaluate toward improving KLS.

7 (a)	**KLSA:** Assemble onscreen diagrams to depict multiple biomolecular scenarios.	Assemble scenarios into a blank space to guide concept development.	MCQ. Verbal and written feedback from students on experience.
7 (b)	**KLSM:** Assemble onscreen diagrams to depict multiple biomolecular scenarios.	Assemble scenarios over neutral pre-assembled diagrams to guide concept development.	MCQ. Verbal and written feedback from students on experience.
7 (c)	**KLSR:** Outline key concepts using question guided recall to learn & recap the lesson.	Outline key concepts using question guided recall to guide concept development.	MCQ. Verbal and written feedback from students on experience.
7 (d)	**Control:** Employ traditional methods of study, e.g., writing notes, to learn & recap lesson notes and diagrams.	Student choice to take notes, highlight, create mind maps, etc. to guide concept development.	MCQ. Verbal and written feedback from students on experience.

5.4.2 Stages of Research and Design

Further improvement in KLS delivery, interaction and lesson layout was required as identified by the student feedback. This led to a small pilot study to assess the enhanced KLS PowerPoints in August 2020. A pre-test of the lesson was delivered to 4 volunteers (one for each study condition) who had no science background and were outside academia, to ensure the KLS lesson and MCQ was operational and understandable for those who might volunteer from other disciplines (see Figure 5.13). There were no issues identified.

To better understand whether kinaesthetic learning depended on both recall and the act of assembly, or whether the assembly act alone was sufficient for learning, the assembly interaction tasks were separated into two new groups, KLSA (assembly & recall) and KLSM (assembly without recall). These were almost identical to the Unguided Assembly and Guided Assembly PowerPoints outlined in Chapter 3, section 3.5. A new comparison group was introduced, the KLSR condition (prototype of Question Guided Recall, section 3.5, iv) based on Karpicke's 'retrieval-practice' (Karpicke & Blunt, 2011), and which used cued recall question tasks (Schneider et al., 2018). The traditional control group was retained as a baseline comparison for all groups until the KLSR group would prove at least as effective.

E. coli Bacteria's Diet Plan!

Escherichia coli (*E. coli*) are bacteria that live in the gut of humans and animals. In the gut, *E. coli* feed on sugar for energy.

Glucose is the simplest of all sugars to breakdown and convert into energy in the form of ATP. For this reason, *E. coli* favour the use of glucose over other sugars.

E. coli can also feed on the sugar lactose but, lactose is a more complex sugar than glucose to breakdown and is slower to convert into energy.

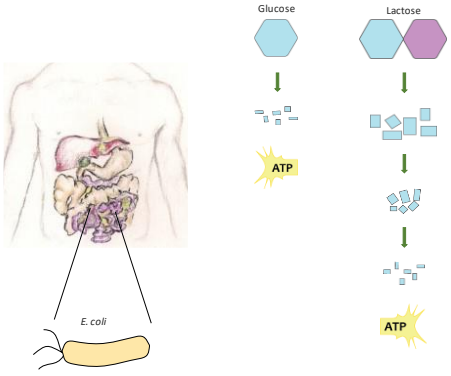
Therefore, if both glucose and lactose are available to *E. coli* at the same time, **they will always feed on glucose first** and will only switch to using lactose when glucose falls below a critically low threshold. From this point on, we refer to levels of glucose that fall below this threshold as being absent.

If glucose is reintroduced, the *E. coli* will return to feeding on glucose and stop using lactose.

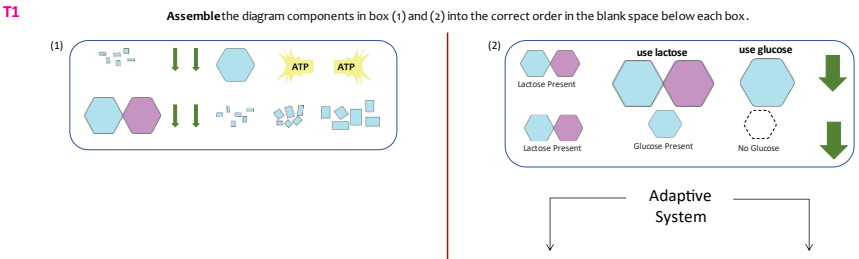
This adaptive system gives *E. coli* an important advantage when competing for food with other bacteria that do not have this adaptive ability.

When lactose is present and glucose is not available, *E. coli* can switch to using lactose by producing specific proteins that can breakdown lactose.

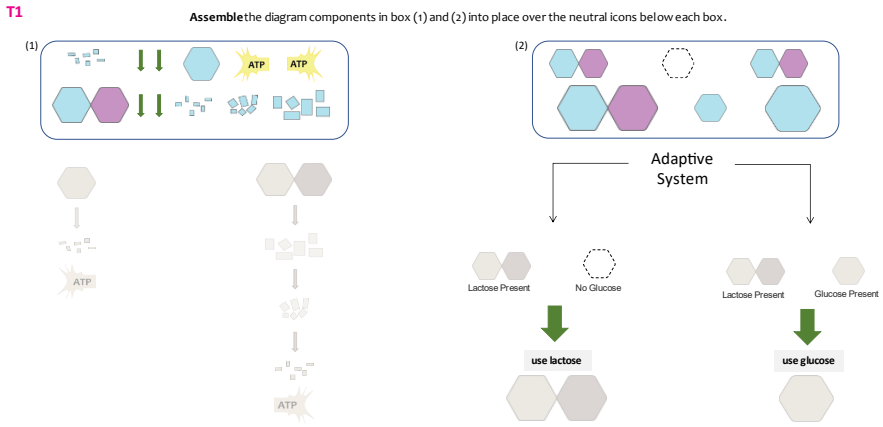
When glucose becomes available again, *E. coli* can turn off production of the proteins for the lactose breakdown and revert to making energy, more efficiently, from glucose.



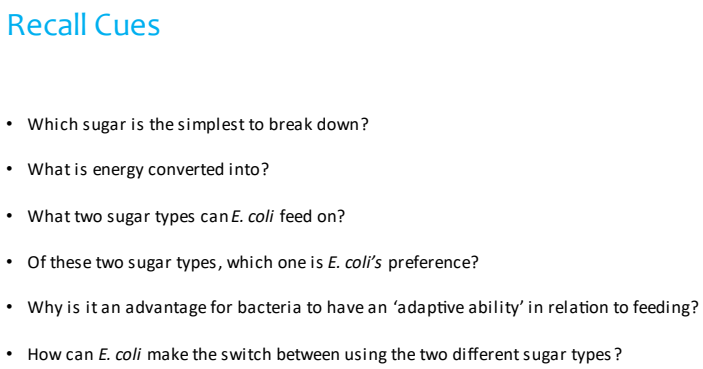
5.13.i Sample Lesson Notes Slide



5.13.ii Sample KLSA (Unguided Assembly) Task Slide



5.13.7.iii Sample KLSM (Guided Assembly) Task Slide



5.13.iv. Sample KLSR Task Slides

Figure 5.13 Experiment 3 Sample Slides. Each lesson slide was followed by a task slide. There were no task slides for the control condition.

Twelve students from multiple disciplines across both undergraduate and postgraduate courses at UCC were randomly recruited to participate in a single timepoint pilot study, through the UCC university wide survey system. Once students had supplied the required permissions, they were randomly assigned across the KLSA, KLSM, KLSR and control groups in Excel until all cells were filled. Despite the provision of several date and time options for participation within a specified 2-week period (see Figure 5.14), four students failed to respond on the day and time they had chosen. This resulted in variation across the cell sizes, with four remaining students in the KLSA group, two in the KLSM group, one in the KLSR and one in the control.

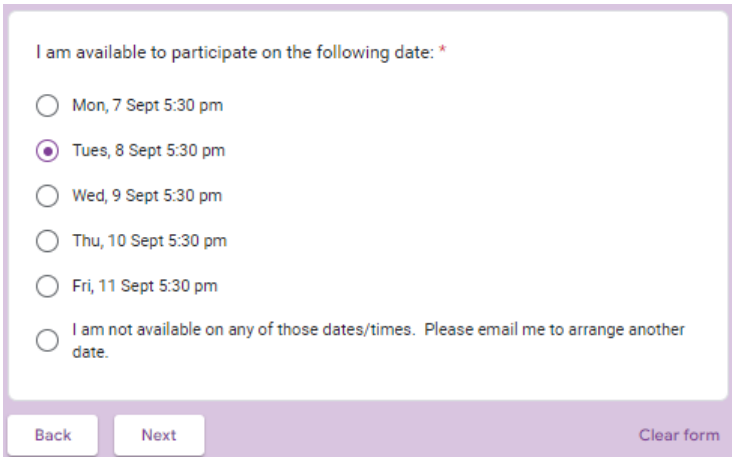


Figure 5.14 Experiment 3 Time Options. Students selected the most suitable time for them to participate in the KLS study.

The average age of participants was 26.75 years (SD 13.08, range 21 – 59 years), comprising 6 males and 4 females. No student identified as being registered with UCC for a learning disability and all participants selected English as their first language, except for one female who did not answer the question. The two students who stated they had prior biological science knowledge at third level were randomly assigned to the KLSR and control groups. As instructions were fully comprehensive and specific to the assigned condition, students were able to proceed independently through their respective PowerPoints.

All KLS PowerPoints were adapted as per the advice of student feedback from Experiment 2. Explicit instructions for downloading the PowerPoint and enabling its use were inserted in the title slide in written format instead of video format (see Figure 5.15). Hence, if students attempted to open the PowerPoint directly from the email instead of downloading it, they would see immediately the correct course of action to take. This simple move reduced almost all reports of technical difficulties encountered previously, suggesting the likelihood that students in the previous experiment were 'skimming' (Carr, 2011) over the email instructions.

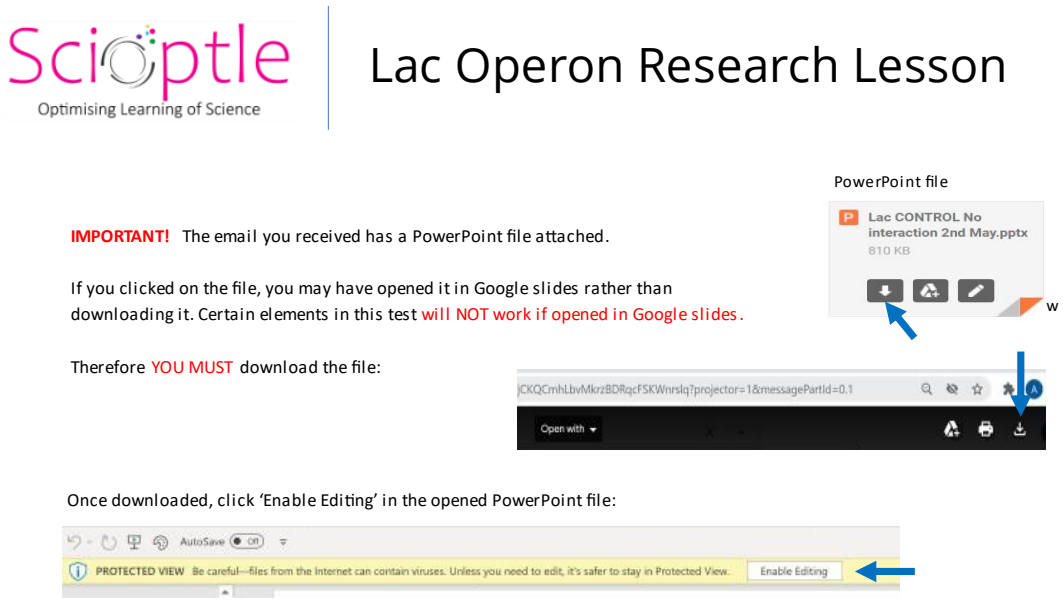


Figure 5.15 Sample Title Slide. Adding instructions to the title slide detailing how to download the PowerPoint attachment, reduced almost all 'technical difficulties' reported in the previous two pilot studies.

5.4.3 Procedure

The KLS PowerPoints were delivered as an attachment to participating student email accounts from the dedicated SCIOPTLE email and at a designated time. This was the method of delivery for all subsequent experiments. For this particular experiment, students participated asynchronously and the study began at the time of participation selected by the student. In the email, students were instructed to open their PowerPoints 15 minutes prior to the start time of the 1 hr session to facilitate full reading of all instructions. The start of the 1 hr study session was marked by playing a ~12-minute animated video of the Lac Operon lesson, inserted as a hyperlink to YouTube within the PowerPoint. This was the same video used in Experiment 2 except it was trimmed using Camtasia video editor to remove silent gaps between slides so the overall flow of the video was seamless. A musical intro and outro were added to make the lesson and instructions more engaging (link to upgraded Lac Operon animation: https://youtu.be/Mti9I7fDKwc).

To control the start time across all study conditions, the video remained disabled in the researcher's SCIOPTLE YouTube channel up until the official start time, at which point the link was enabled. Students were instructed that the video would only be played once, after which time the video would be disabled. An advantage of using YouTube is that student engagement with the video could be tracked live in YouTube analytics. Immediately after viewing the video, students proceeded through the rest of the lesson slides. The lesson slides (containing the lesson notes and diagrams) were identical for all conditions. Each lesson slide was followed by a study condition slide which provided a specific learning approach toward recalling and understanding the content of the previous slide. Students followed the instructions related to the study condition that they were assigned, on how to engage with the study tasks specific to their condition.

In the KLSA group, students were presented with 7 task slides which contained a selection of individual picture elements (icons) from the previous lesson slide displayed in a disassembled state within a box(es) at the top or side of each task slide. Students were given instructions to assemble a particular picture/diagram representing key processes and molecules from the previous lesson slide by using the individual, randomly ordered icons from the box, e.g., *"In the blank space below, assemble all the diagram components in the box, into the correct order to show transcription and translation."*

In the KLSM group, students completed the same tasks as the KLSA group except the icons were assembled over a transparent, neutral diagram which served to guide assembly e.g., "*Assemble all the diagram components in the box, into place over the neutral icons below the box to show transcription and translation."* This required an interactive movement with on-screen content but removed the recall processing required by the KLSA group.

In the KLSR group, students did not engage in any diagram assembly, nor have any diagram components on their task slides. Instead, they were instructed to mentally complete a series of questions which guided recall for key processes and molecules from the previous lesson slide. This was to provide them with the same advantage as the KLSA and KLSM groups who received instructions on assembling key processes and molecules. Students were instructed not to write their answers down but to treat the questions as "*memory cues to help you recall the lesson*." In the control group, students did not have any task slides and were instructed to *"*use whatever study method(s) you would normally use to help you learn the lesson content, e.g., taking notes, highlighting onscreen, making mind maps etc.*"*

Students across the three test conditions were instructed not to employ any other method of study outside of what was provided in the study tasks and not to refer to the previous slide while completing a task. Students were free to consult the previous lesson slide once they had attempted assembly/cued recall to self-assess their knowledge against the 'expert' version but were instructed not to alter their original assembly attempt. They were reminded that this was a specific learning technique, not an exam. Students proceeded to the assessment quiz in Google Forms immediately after the 30 min study session to complete an MCQ of 20 recall and transfer questions (see Appendix B, Figure B.1). Questions 1-16 of the quiz related to recall, for example:

Q3. In which of the following scenarios is the Lac Operon being repressed?

a) RNA polymerase is transcribing the Lac genes
b) The Lac proteins are being produced
c) RNA polymerase is bound to the Lac operon, but the Lac Z-Y-A genes are not being transcribed
d) The Lac repressor is not bound to the Lac operon
e) Allolactose has altered the structure of the Lac repressor

The correct answer is (c)

Questions 17-20 tested for transfer knowledge, e.g.:

Q17. Assume that the gene encoding Permease has been deleted from E. coli. Predict the outcome for the Lac operon.

a) The entry of lactose into the E. coli will be enhanced
b) E. coli will not grow well on a medium containing lactose and glucose
c) E. coli will grow well on a medium containing only lactose
d) Lactose can no longer enter E. coli from the external environment
e) E. coli will not grow well on a medium containing only glucose

The correct answer is (d)

Correct questions were given a mark of 5 and incorrect, a mark of 0.

5.4.4 Methodology of Analysis of Results

As per previous experiments with the exception that feedback was not analysed in NVIVO as it was limited.

5.4.5 Experiment 3 Results

Results were downloaded into Excel and the mean of each group calculated as follows: KLSA (*n* 4, *M* = 75%); KLSM (*n* 2, *M* = 87.5 %); KLSR (*n* 1, *M* = 65%); Control (*n* 1, *M* = 35%). As there was only a single participant in the KLSR and Control groups, it was not possible to make any practical inferences from the results of the MCQ and a boxplot of the data are not included.

5.4.6 Experiment 3 Discussion

Despite significant efforts to accommodate participation in this study, the number of volunteers remained low. Nonetheless, the main purpose of this pilot study was to ensure that students across all groups could implement instructions and complete all aspects of online interaction without the technical difficulties encountered in the previous Experiment 2.

All students completed the PowerPoints and MCQ successfully as per study protocol. Although the video lesson was just over 12 minutes in length, it covered the same depth and detail of content normally delivered in the 1-hour lecture from which it was adapted. This proved a highly efficient method of lesson delivery as the animation was uninterrupted and did not require focus on external items during delivery such as, lecture notes / textbooks / PowerPoint slides, etc. This may have bolstered image formation for learning through visualisation of the active processes involved in the Lac Operon, in advance of studying the notes. In addition, the separation of the PowerPoint into a lesson slide followed by task slide provided a

strong structure for stepwise learning. This served to re-enforce key learning outcomes to the student as they progressed through the lesson.

Despite the low participation, a positive outcome is that both kinaesthetic assembly groups (KLSA and KLSM) returned strong grades. In light of the previous two pilot studies, this further confirmed the usability of an online KL assembly technique in PowerPoint for science learning. No technical difficulties were reported and all students completed the study and MCQ according to instructions. The next goal was to scale up the study for testing among a larger student cohort.

CHAPTER 6

EXPERIMENT 4

6. Two timepoint KLS study of KL assembly techniques vs. question guided recall of notetaking online

6.1 Experiment 4 Study Objectives

I. *Test the KLS for its effectiveness in sustaining learning as it is required in reality to last over a period of time.*

II. *Develop a simple qualitative coding system for demographic details suitable for application to large sample sizes and supportive of maintaining the anonymity of students.*

III. *Create a reliable grading rubric suitable for application to both recall and transfer short answer questions (SAQs).*

Table 6.1 Check for Constructive Alignment of Lac Operon Lesson Experiment 4

	Learning Outcome	Teaching & Learning Activities	Assessment
1)	Categorise & order the structural components of the Lac Operon.	Synchronous self-directed learning. PowerPoint lesson & study tasks.	Online MCQs completed post-study & SAQs 7 days later. Includes recall questions and questions involving transfer of knowledge and understanding to new scenarios.
2)	Connect the function of regulatory molecules with their binding sites & temporal order, in response to sugar type.	As above.	MCQs and SAQs as above.
3)	Relate changes in the presence of glucose & lactose to positive & negative regulation.	As above.	MCQs and SAQs as above.
4)	Predict the outcome for regulation & function of the Lac Operon given a number of novel hypothetical scenarios.	As above.	Transfer questions in MCQ & SAQ will assess whether learning can be applied to novel, hypothetical scenarios.
5)	Complete all aspects of the study as directed by researcher & in compliance with study parameters & ethical standards.	Student completion of Participant Questionnaire & Consent Form. Participation in study & MCQ.	Return of Participant Questionnaire & Consent form. Completion of study, MCQ & SAQ.

6)	Provide insight & guidance on the design, delivery & assessment of the KL lesson & quiz.	Student to relate feedback verbally and/or via email.	Communicate with student in response to feedback & evaluate toward improving KLS.
7 (a)	**Unguided Assembly:** Assemble onscreen diagrams to depict multiple biomolecular scenarios.	Assemble scenarios into a blank space to guide concept development.	MCQs & SAQs. Verbal and written feedback from students on experience.
7 (b)	**Guided Assembly:** Assemble onscreen diagrams to depict multiple biomolecular scenarios.	Assemble scenarios over neutral pre-assembled diagrams to guide concept development.	MCQs & SAQs. Verbal and written feedback from students on experience.
7 (c)	**Question Guided Recall:** Outline key concepts using questions to learn & recap the lesson.	Outline key concepts using question guided recall to guide concept development.	MCQs & SAQs. Verbal and written feedback from students on experience.

6.2 Stages of Research and Design

Eighty undergraduate students from the first-year medicine subject pool at UCC were randomly recruited for participation in this two timepoint KLS study and the required permissions submitted. A power analysis was conducted prior to recruitment using G*Power 3 software (Faul, Erdfelder, Lang & Buchner, 2007) which indicated the ideal sample size for 3 comparison groups with a large effect size (0.4) should be 102 participants (see Figure 6.1). Students were recruited as previously, through invitational email and lecture address and were offered bonus lectures on how to improve exam performance as an incentive to volunteer. Ninety students initially signed up for participation and their details anonymised through coding in Excel before random assortment into three different study conditions: Unguided Assembly, Guided Assembly and Question Guided Recall (section 3.5, iv). Students remained in the same group for both timepoints. The first stage of the study, timepoint 1 (T1), was conducted on the 27th of October 2020 and the second stage, timepoint 2 (T2), was conducted 7 days later, on the 3rd of Nov 2020. The set-up for T1 was to have the study session followed immediately by the MCQ as conducted in the pilot studies. In T2, students received a link for an online quiz by email which became active at an assigned time. Once students completed this 20-minute T2 quiz, their participation in the study was over.

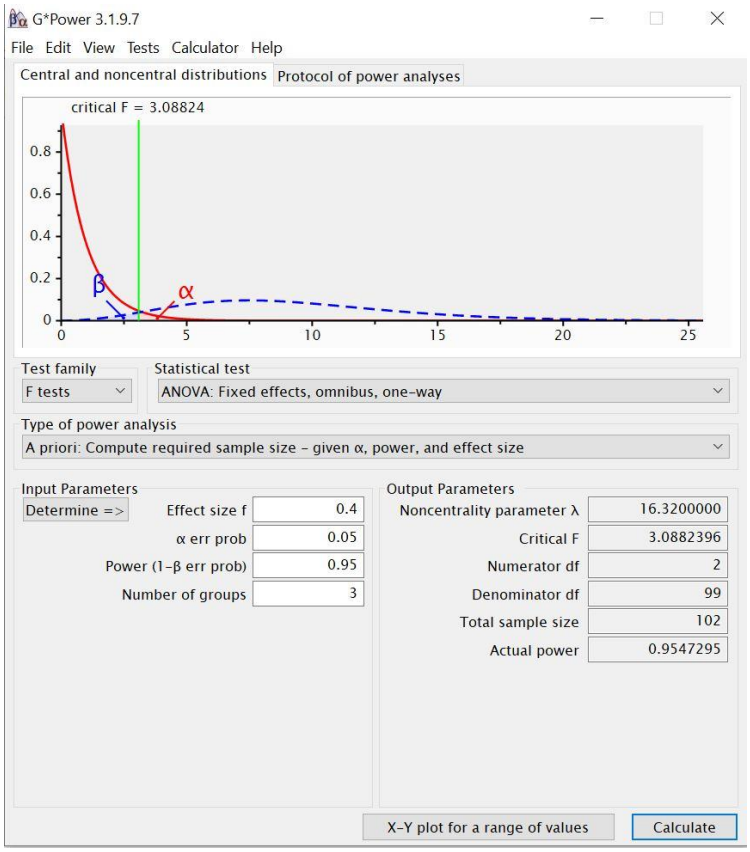


Figure 6.1 G*Power Analysis for Experiment 4. A-priori power analysis indicating the ideal sample size for 3 comparison groups with a large effect size (0.4) should be 102 participants.

Each student received a unique 4-digit code by email for use in place of their student emails/names while participating in the study. Further codes were generated in Excel based on key information supplied by the student on how easily distracted they were, and whether they used a touchscreen, trackpad or mouse. Levels of distraction were graded A to E, with A being for 'not easily distracted' and E being for 'very easily distracted.' The letter 't' was assigned to users of touchscreen / trackpad or left blank for a mouse and 'd' for students registered with UCC as having a learning disability. Male participants were highlighted in bold and prior science (e.g., a module or course taken in any science subject) at 3rd level was also taken into account.

The 'custom sort' tool in Excel was used to sort the students in ascending order from A to E and then students were randomly assigned to all groups until all cells were filled, beginning with the first student under 'A' and finishing with the last student under 'E.' Thus, the 90 students were balanced as evenly as possible

across the three separate study conditions to be approximately equivalent for gender, level of distraction and use of touchscreen/trackpad or mouse. Table 6.2 presents the groups which were balanced based on demographic details supplied by students.

Table 6.2 Demographic Balance of Groups for Experiment 4

	KAMAR	KMOV	KREC
Male	5	5	7
Female	23	23	22
No gender ID			
Learning disability	1	1	0
Prior science	6	5	5
Touchscreen/trackpad	19	19	19
Levels of Distraction (A rarely : E very easily)			
A	2	2	2
B	5	5	3
C	10	9	9
D	9	10	11
E	4	4	4

Ten participants failed to respond on the day of testing leaving the final groups balanced for T1 as follows: Unguided Assembly (*n* 27), Guided Assembly (*n* 28), Question Guided Recall (*n* 25).

6.3 Study Conditions

In the Unguided Assembly and Guided Assembly groups, the lesson included 8 task slides, the first 7 of which were closely similar in presentation to Experiment 3. These two interactive groups were previously titled KLSA and KLSM respectively. An additional task slide was added with an assembly task for the final recap slide. In the Question Guided Recall group, students did not engage in any diagram assembly, nor have any diagram components on their task slides. Instead, they were instructed to type the answers to a series of questions across 9 task slides which guided recall for key processes and molecules from the previous lesson slide, including for the recap slide. This was to provide the Question Guided Recall group with the same advantage as the unguided and guided assembly groups who received instructions on assembling specific key processes and molecules, e.g.,

"Using knowledge that you have learned from the previous slide, please answer the following questions with concise short bullet points or single word answers. All questions are with respect to E. coli, glucose / lactose metabolism and the lac operon. Please type your answer under the questions."

Students in the Question Guided Recall group typed their answers directly into the PowerPoint task slide below each question.

Strategic note taking in a computer format vs. longhand has proven an effective learning approach (Bui, Myerson, & Hale, 2013; Chi & Wylie, 2014). This Question Guided Recall group was an amalgamation of Karpicke's retrieval practice approach (Karpicke, 2011) and Bui's computer note-taking approach using questions to cue recall. Thus, the Question Guided Recall group (recall without assembly) was an amalgamation of recall techniques considered highly effective in current literature. The control group used in previous pilot tests was dropped in favour of the more challenging Question Guided Recall group as a comparison to the kinaesthetic Unguided Assembly group and Guided Assembly group. If results showed no significance but grades were comparably close, it would indicate that the kinaesthetic assembly groups may be at least as effective as note-taking and retrieval practice; and if significance was found, the results interpreted accordingly.

6.4 Procedure

This two-timepoint KLS study involved an initial learning session with immediate post testing for short-term learning, followed one week later by a quiz only session to measure long-term learning retention. Participation in T1 was similar to that described in Experiment 3, including downloading and reading the lesson protocol instructions (15 min), viewing the animated video lesson (12 min), learning through completion of assigned study tasks (30 min), and completion of the same MCQ quiz in Google Forms (20 min). Correct questions were given a mark of 5 and incorrect, a mark of 0.

Participation in T2 (20 min SAQ) did not require any further engagement with the lesson. Students were asked not to study any material on the Lac Operon prior to the T2 session scheduled 7 days later. It was highlighted to students that the purpose for this was to test if their assigned study tasks would benefit their long-term knowledge retention. At a designated time, students were simultaneously emailed a link to a short answer quiz (SAQ) titled, '*Knowledge Retention Quiz'*, comprising 15 short answer questions in Google Forms. Questions 1-9 of the SAQ related to the recall of lesson details and required the student to type their answer onscreen into the Google Form. A grading rubric was developed for marking the SAQ, with total points possible per fully correct answer being 2, and with least points possible being

0.5. Completely incorrect answers received a mark of 0. As this was a test for knowledge retention, marks could be adjusted by increments of 0.25 according to detail/accuracy, but not lower than 0.5 unless a grade of 0 was appropriate. For example, the following shows the answer key for assigning a grade to Q.1.:

Q1. "What is the name and function of the protein encoded by the Lac Y gene?"

- *Total points possible = 2*
- *1 point for correct name of the protein (allow for slight misspelling) and 1 point for function i.e., enables lactose to enter E. coli cell.*

Questions 10-15 tested for transfer knowledge and required the student to enter as much detail as they could recall into the answer box onscreen in the Google Form. The following shows the answer key to assign a grade for Q.12.:

Q12. "Assume you created a mutant E. coli where you deleted the Lac Z gene from the E. coli genome. Predict the effect that this deletion would have on transcription of the Lac genes in E. coli grown on a media in which glucose is absent and lactose is present?"

- *Total points possible = 2. Adjust by increments of 0.25 according to detail/accuracy.*
- ***Full marks:** if the student can predict that the absence of the Lac Z gene means lactose cannot be broken down and therefore transcription cannot proceed as allolactose is not present to lift repression of Lac genes.*
- ***1.75 points:** if student states similar to above but neglects to say that transcription cannot occur.*
- ***1.5 points:** if student recognises that lactose cannot enter the cell and that E. coli will not survive.*
- ***1 point:** if absence of Beta galactosidase means lactose cannot be broken down into glucose and galactose.*
- ***0.75 points:** if absence of gene means there's no breakdown of lactose*
- ***0.5 points:** if student simply states that transcription will proceed as this is a 50/50 guess.*

A flowchart was drawn up for this experiment to guide the multiple steps involved (see Appendix F).

6.5 Methodology of Analysis of Results

Two assessors were assigned to mark the SAQ, one of whom drew up the rubric in and trained the other assessor in advance of manually marking the results independently in Google Forms. Quiz results were downloaded into a .csv file,

saved as an .xlsx file, tidied in Excel and then extracted for statistical analysis in SPSS (version released 2021).

The one-way between groups *Analysis of Variance* (ANOVA) test is used to compare the means of three or more independent groups with normally distributed and randomly assigned samples (Pallant, 2011). SPSS provides formal tests for normality such as the *Kolmogorov-Smirnov* test or *Shapiro-Wilk* test but without SPSS, a normal distribution can be checked visually using histograms which should display a bell-shaped curve. Alternatively, equal variances for normality can be checked by observing the standard deviations of the comparison groups. The largest standard deviation (SD) should not be more than twice that of the smallest SD. In such cases, unequal variances are assumed and the non-parametric equivalent of the ANOVA is used, the *Kruskal-Wallis* test.

In a one-way ANOVA, multiple comparisons of all the groups' means are made, meaning that overall significance can be detected but at group level, the pairwise comparison of group means cannot display significance unless a post hoc test is applied and if no significance is detected, there is no need to apply a post hoc test. There are several post hoc tests and two of the most common for ANOVAs are the *Dunnett's* test, used to compare two or more groups to a baseline group; or the *Tukey Honestly Significant Difference* (HSD) test, used to compare all the means from each of the groups (Pallant, 2011). Once applied, the post hoc test can reveal the direction of significance across groups, e.g., group A is significantly better than group B but not group C; group C is significantly better than A and group B, etc. The results of both timepoint quizzes were downloaded into excel and sorted by group before transferring into SPSS for statistical analysis. All groups were independent and had a normal distribution with randomly assigned students. Hence, the most appropriate statistical test to use for each timepoint was the ANOVA and post hoc Tukey HSD test.

Effect size measures the magnitude that a statistically significant outcome can be attributed to a test condition. Eta squared and Cohen's *d,* are effect size statistics but the latter relies on similar standard deviations amongst groups (Pallant, 2011). Pallant explains how Cohen's *d* is a measure of the standard deviation between the means whereas Eta squared reflects the "*proportion of variance of the dependent variable that is explained by the independent variable*" (Pallant, 2011, p. 210). When Cohen's *d* cannot be used, *"Glass's delta, which uses only the standard*

deviation of the control group, is an alternative measure if each group has a different standard deviation" (p. 210). Eta squared can be calculated in SPSS for ANOVA but is only reported for statistically significant results.

A correlation analysis is used to measure the relationship between variables and is suitable for both quantitative and qualitative data. For this experiment, correlation analyses were conducted to reveal any relationship between correct assembly of diagrams and grade outcome. To run the correlation on assembly tasks, a novel approach was required to quantify the concepts expressed in the form of correctly assembled scenarios. An interactive PDF assembly rubric (link: https://tinyurl.com/KLS4AssemblyRubric) was created to assign points to each slide based on the number of concepts correctly assembled as per instructed. Points for task assembly were entered into Excel, along with grades for T1 and T2 for each student, before transferring to SPSS for analysis.

6.6 Experiment 6 Results

One-way between group ANOVAS (with α significant at $p < 0.5$) revealed no statistically significant difference between the groups Unguided Assembly, Guided Assembly and Question Guided Recall for age (M = 19.33 yrs, SD = 2.03, p = .340), or gender (p = .838). Nor did the groups differ significantly with respect to academic ability (2020 CAO course entry points range 731-792) or English language fluency.

The null hypothesis for the independent samples (Unguided Assembly vs. Guided Assembly vs. Question Guided Recall) stated there was no difference between group means for learning (H_0:$\mu_1 = \mu_2 = \mu_3$). The alternative hypothesis stated that at least one pair of means would differ from each other for learning (H_A: $\mu_i \neq \mu_j$, for at least one pair of groups where i, j = 1, 2, 3 and $i \neq j$). Results returned were as follows, (Question Guided Recall n 25, M = 87%; Guided Assembly, n 28, M = 80%; Unguided Assembly, n 27, M = 77%).

There was marginal statistical significance for learning between group means as determined by a one-way between groups ANOVA (with α significant at $p < 0.5$), $F(2,77) = 2.979$, p = .057. A post hoc Tukey HSD test revealed a statistically significant difference for learning between the Question Guided Recall and Unguided Assembly groups (p = .052), 95% CI = [-.08, 20.38] and the null

hypothesis was rejected. We failed to reject the null hypothesis for the remainder of group comparisons (see Figure 6.2 a).

One week later, students were emailed a link at 1:55 pm for access to the SAQ quiz set to begin at 2 pm. Students were advised they had 20 min to complete the 15-question quiz. No group returned all results within the allotted time frame and the timestamp for results submitted beyond 2:25 pm was highly variable. Therefore, results beyond this timepoint were excluded. Five participants results were excluded from the Unguided Assembly group, 5 from the Guided Assembly group and 10 from the Question Guided Recall group.

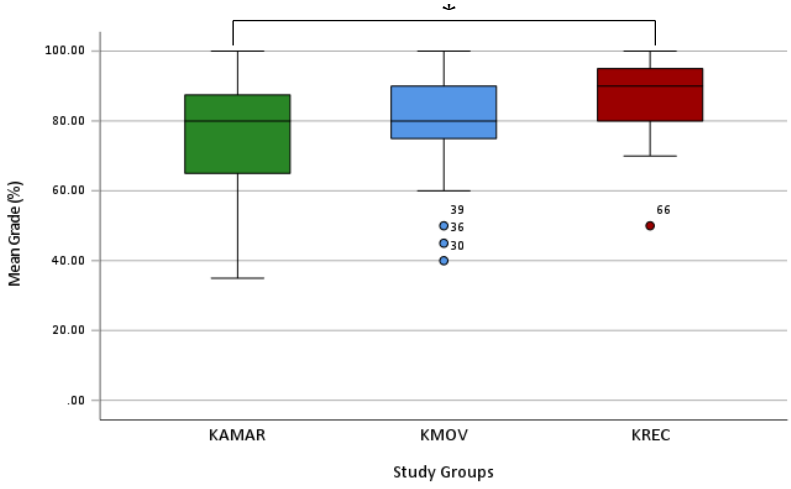


Figure 6.2 (A) Experiment 4 Comparison of Mean Grade for Unguided Assembly vs. Guided Assembly vs. Question Guided Recall. Boxplot results from T1: Unguided Assembly (*M* = 77%) vs. Guided Assembly (*M* = 80%) vs. Question Guided Recall (*M* = 87%).

A one-way between groups ANOVA (with α significant at $p < 0.5$) revealed a statistically significant difference in long-term learning retention across the three different study conditions (Unguided Assembly, *n* 21, *M* = 33%; Guided Assembly, *n* 22, *M* = 25%; Question Guided Recall, *n* 18, *M* = 43%); $F(2,58) = 7.894$, $p < .001$, and with a large effect size calculated ($\eta^2 = .214$). A post hoc Tukey HSD test revealed a higher retention of learning which was statistically significant for the Question Guided Recall vs. Unguided Assembly groups ($p = .016$), 95% CI = [2.36, 27.63] and the Question Guided Recall vs. Guided Assembly groups ($p < .001$), 95% CI = [7.66, 32.43] and the null hypothesis was rejected. There was no statistically

significant difference between the Unguided and Guided Assembly groups (p = .556) and we failed to reject the null hypothesis (Figure 6.2 b).

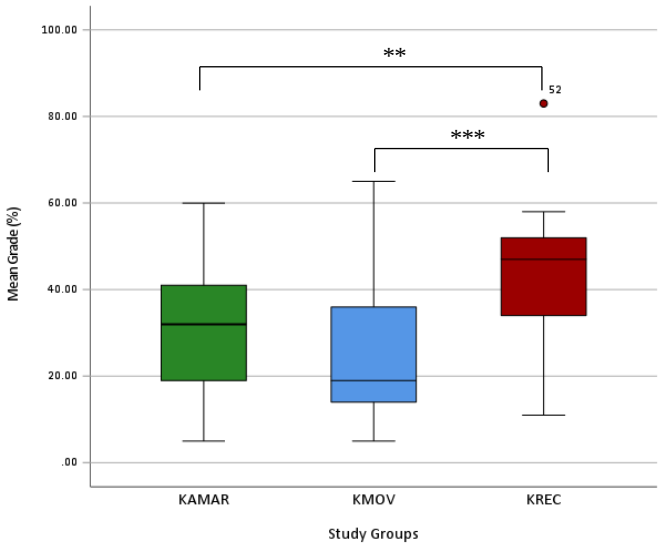


Figure 6.2 (B) Experiment 4 Comparison of Mean Grade for Unguided Assembly vs. Guided Assembly vs. Question Guided Recall. Boxplot results from T2: Unguided Assembly (M = 33%) vs. Guided Assembly (M = 25%) vs. Question Guided Recall (M = 43%)

A Pearson correlation coefficient was performed to assess the linear relationship between the correct assembly of tasks and grade outcome for the Unguided Assembly group. Although not statistically significant, there was a moderate positive correlation between the two variables for T1, $r(22) = .38$, $p = .065$ (see Figure 6.3 a). A low positive correlation was found to persist between the two variables seven days later from T2 results, $r(20) = .15$, $p = .516$ (see Figure 6.3 b). A single anomalous outlier presented reverse results from the remainder of the participants in that they returned a low grade for correct assembly of the Unguided Assembly PowerPoint (~40%) yet returned very high grades of over 90% in T1 and ~60% for T2. As this was not an expected or credible outcome, it was necessary to remove this outlier and re-run a Pearson correlation coefficient.

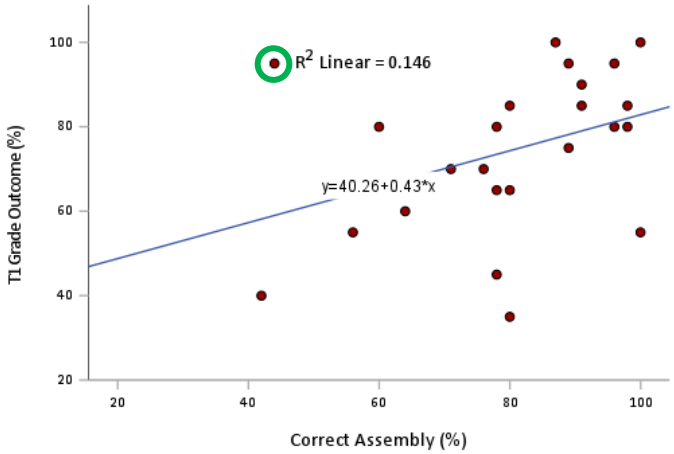


Figure 6.3 (A) Initial Pearson Correlation Analysis of Timepoint 1. A moderate positive correlation was found to exist between successful completion of Unguided Assembly scenarios and subsequent grade outcome, though not to a statistically significant level. One anomalous result (circled in green) presented as having poor assembly yet high grades in the T1 quiz.

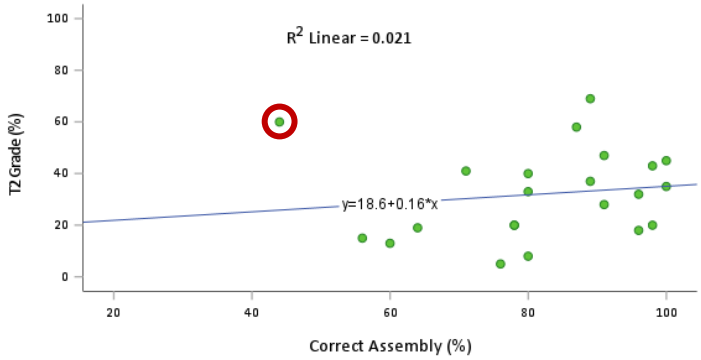


Figure 6.3 (B) Initial Pearson Correlation Analysis of Timepoint 2. A low positive correlation was found to persist between successful completion of Unguided Assembly scenarios and subsequent grade outcome. The same outlier (circled in red) presented anomalous results for Timepoint 2.

Removal of this single anomalous outlier returned results that were statistically significant. There was a strong positive correlation between the two variables for T1, $r(21) = .57$, $p = .005$ (see Figure 6.4 a). Two participants (not outliers) did not take the quiz in T2 and consequently, their assembly results were not included in the T2 analysis. Their removal did not alter results. A moderate positive correlation

was found to persist between the two variables seven days later for T2, $r(19) = .44$, $p = .045$ (see Figure 6.4 b).

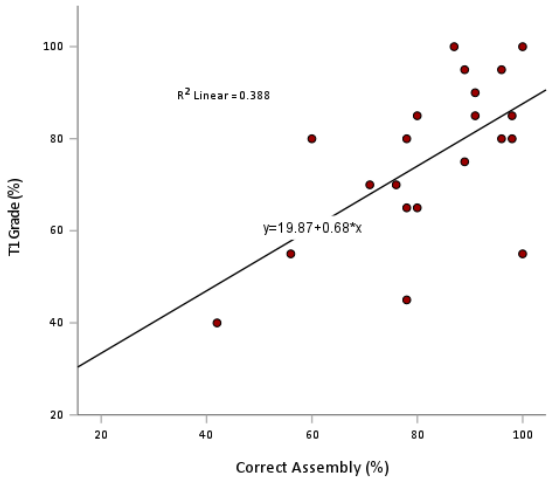


Figure 6.4 (A) Second Pearson Correlation Analysis with Outlier Removed. A high positive correlation was found to exist between successful completion of Unguided Assembly scenarios and subsequent grade outcome to a statistically significant level (p = .005)

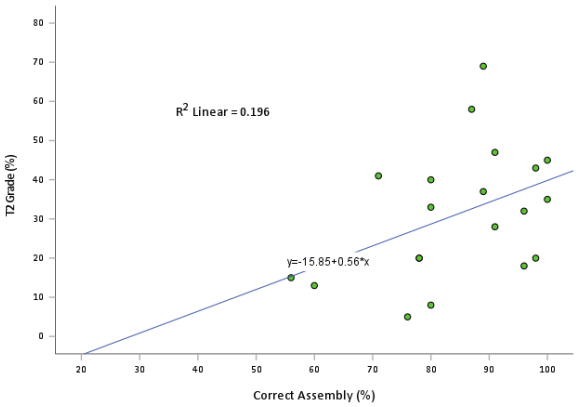


Figure 6.4 (B) Second Pearson Correlation Analysis of Timepoint 2 with Outlier Removed. A moderate positive correlation was found to persist seven days later between successful completion of Unguided Assembly scenarios and subsequent grade outcome to a statistically significant level p = .045).

6.7 Experiment 4 Discussion

Unlike the T1 quiz which was set-up to be graded automatically in Google Forms, the results for the T2 quiz had to be corrected manually by two independent

assessors, according to the rubric drawn up by this researcher. The mean grade/group for all results submitted were:

- *Assessor 1*: Unguided Assembly = 30%, Guided Assembly = 26%, Question Guided Recall = 40%
- *Assessor 2*: Unguided Assembly = 31%, Guided Assembly = 26%, Question Guided Recall = 38%

These results show high inter-assessor reliability when following the rubric. When averaged in Excel, the results of the combined SAQ grading were:

- Unguided Assembly = 31%, Guided Assembly = 26%, Question Guided Recall = 39%

Results were further adjusted to remove any students who had not complied with the time for submission of Quiz 2, as recorded by the timestamp in Google Forms. The adjusted results for T2 were as follows:

- Unguided Assembly = 30%, Guided Assembly = 25%, Question Guided Recall = 43%

The jump in grade for the Question Guided Recall group from 39% to 43% in contrast to the 1% difference between the adjusted grades of the other two groups indicates much more variability in the Question Guided Recall group results. The high exclusion rate from the Question Guided Recall group may signify a struggle for recalling the lesson from the previous week. Alternatively, the number of questions that required answering may have required more time to answer than the study allowed but this is unlikely given that the previous experiment employed a similar question format which was completed within the same timeframe.

Both timepoint quizzes were treated as stand-alone tests due to the difference in their format and difference in question type so it was not feasible to measure loss of learning linearly over time. However, it is interesting to note that while the Guided Assembly group outperformed the Unguided Assembly group by a grade difference of 3% in T1 (Guided Assembly M = 80% vs. Unguided Assembly M = 77%), in T2 the Unguided Assembly group appear to have gained more robust long-term learning retention by a grade difference of 8% (Unguided Assembly M = 33% vs. Guided Assembly M = 25%). This indicates that the Guided Assembly condition is suitable for recalling information well when it is required in the short-term, but for

learning that requires good short-term in addition to long-term retention, the Unguided Assembly approach may be a more suitable study technique to employ.

The Question Guided Recall group proved to be the most non-compliant across both time points in terms of adhering to the timing of the study. They returned the highest results for both the T1 (M = 87%) and T2 (M = 43%) quizzes. It should be noted that the removal of ten students from this group in T2 resulted in an increase to the mean grade by 4%. Thus, the time cut-off may have inadvertently enhanced the perceived performance of the Question Guided Recall group. Larger sample sizes or more compliance across all groups may have returned a different outcome. For this reason, these results should be treated with caution and not generalised to the wider population.

There were some positive observations from this study. In the Unguided Assembly group, tasks completed correctly, especially the more complex tasks, appeared to be fair predictors for a better grade outcome as also observed in Experiment 2. Tasks completed incorrectly appeared fair predictors of a lower grade outcome and areas of the lesson a student struggled with could also be pinpointed. The same was not possible for the Guided Assembly group due to their assembly being guided and therefore, correct assembly of a molecular scenario could not be used as a predictor for high or low, grade outcome for this group.

Similar to the Guided Assembly PowerPoints, completion of the Question Guided Recall tasks were not necessarily good predictors for how a student would perform in the MCQ. In general, those who typed more descriptive answers identified as having prior science (PS) and performed better than those without prior science (NPS), who wrote shorter bullet point style answers. Removal of students with PS did not return a statistically significant result, hence, all group results reported include students with PS.

One of the ethical commitments given to students by the researchers was that any information from which a student could be identified would not be included in the thesis. The table used to match student assembly grades to their T1 and T2 quiz results for the correlation analysis would have revealed a combination of results from which a student might self-identify. Thus, it was not possible to include the table in any section of the thesis.

The unguided assembly of tasks in the Unguided Assembly condition was able to show visually, whether a student had gained a level of understanding for the

lesson content. The single anomalous outlier whose results were removed from the correlation analysis returned a low grade, indicating they were confused during assembly. It seems unlikely then that their immediate post-test quiz would return such a high grade, with their grade in T2 one week later also much higher than the majority of other grades in the Unguided Assembly group. It is possible to speculate as to the reasons why this may have occurred. The student may have rushed the assembly of tasks in favour of spending more time memorising the lesson slides; they may have attempted the tasks and on completion, checked to see if they were correct and subsequently performed better as they were more aware of their mistakes; or they may have simply cheated. Whatever the reason, their removal reduced skewness to the point of strong statistical significance.

The most important outcome of this experiment was the revelation of a strong relationship between how well the diagrams were assembled and subsequent quiz performance at both timepoints. This is very exciting in terms of providing a bespoke, cost effective, low immersion kinaesthetic experience to rival high immersion, expensive and generic approaches such as VR. Research more broadly also supports the use of low immersion platforms over high immersion in terms of learning gains (Makransky et al., 2019). Much time in academia is spent on generating and marking written assignments but here, the Unguided Assembly approach has been trialled successfully as an alternative and reliable yardstick for predictive validity. Thus, the Unguided Assembly format lends itself well for use as both a formative and summative assessment option.

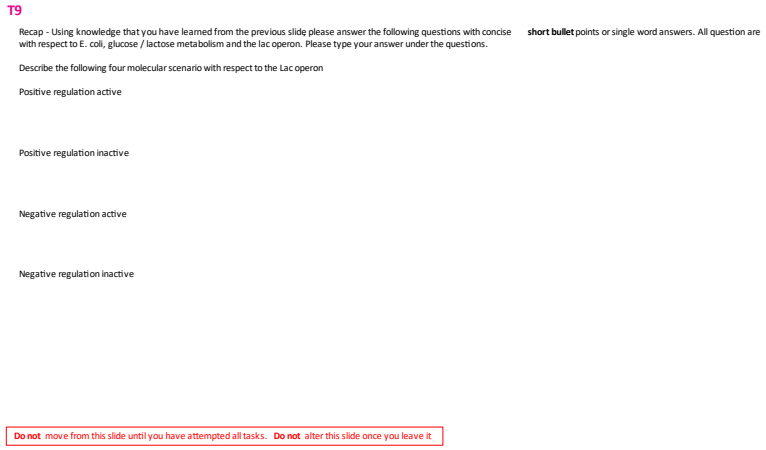
The interactive assembly rubric created by this researcher worked well for converting visual results (assembled diagrams) into quantitative grades. This rubric may provide other researchers with an efficient method for handling variables which are not numeric and could be open to subjectivity. 'Idea units' developed by Rawson & Kintsch (2005) are commonly used in educational psychology research as a system for assigning points to different categories of information, i.e., "*main points, important details or unimportant details."* This rubric for assembly tasks provides an alternative approach for researchers to adopt. Because the rubric is created as an interactive PDF for onscreen use, it can be quickly altered, updated, or shared. Once a particular student's assembly PowerPoint has been assigned points, the rubric can be reset to begin immediately assigning points to the next PowerPoint. Thus, it provides a rapid means of evaluating visual content.

6.8 Limitations of the Study

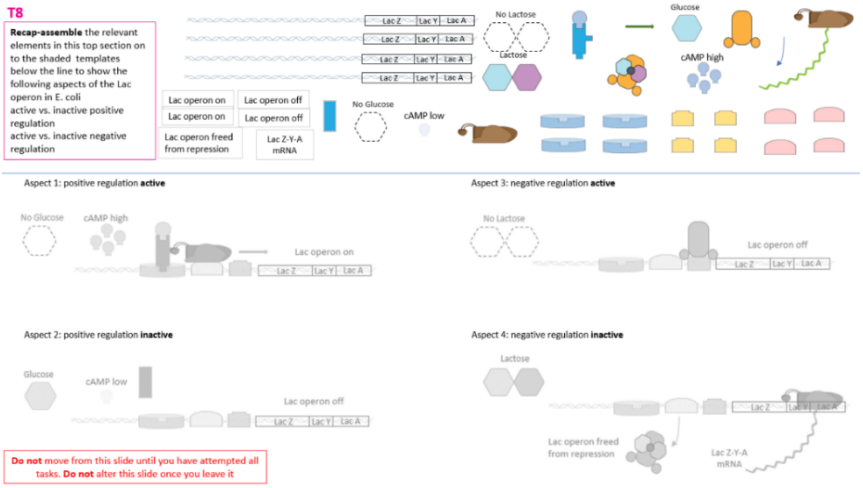
Conducting an a priori power analysis safeguards the misinterpretation of statistical results by ensuring that the minimum number of participants have been recruited. If a small effect size is expected, more participants would be required to detect a statistically significant result but in reality, a medium (o.25) to large (0.4) effect size would be the chosen standard (Faul et al., 2007). The ideal number of participants identified by the power analysis was 102 for 3 groups but the actual number of participants was 84. When sample sizes are less than ideal, post hoc tests can mitigate against detecting a false result. Hence, a post hoc Tukey test was used to reduce the risk of errors in reporting results.

Several problems arose during the running of the T1 study and consequently, the results must be treated with caution. The YouTube video lesson was not disabled during the course of the study as some students joined the session late and requested access. YouTube analytics showed that the video had 91 views during a time point when just under 80 students were actively participating in the session. This suggests that some students failed to comply with the request not to view the video more than once. Inadvertently, it also shows that students found it a useful learning resource by returning to it. The addition of a task slide for the recap lesson slide appears to have been a confounding factor for all groups, with several of the PowerPoints returned illustrating no attempt was made on the final task slide (Figure 6.5 a). As students were non-compliant with the timing of the study, it cannot be concluded that incompletion was due to not having enough time. In addition, some students who had otherwise performed well in assembling tasks went on to struggle with the final task slide, even when assembly was guided (see Figure 6.5 b). The final slide for the Question Guided Recall group was less complex in presentation than that of the Unguided Assembly and Guided Assembly groups. This may go toward explaining why both the Unguided Assembly and Guided Assembly groups struggled to answer the same recall and transfer questions almost equally and in contrast to the Question Guided Recall group, as can be seen in an individual question analysis performed on the results (see Figure 6.6).

A



B



C

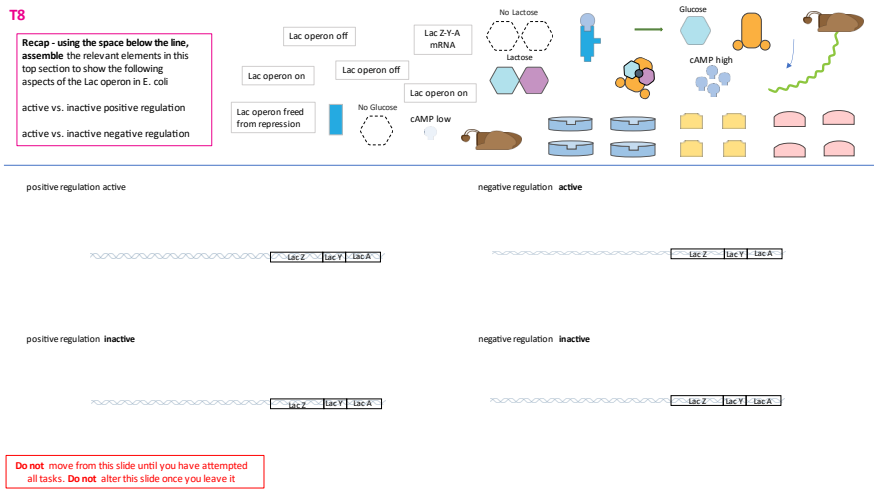


Figure 6.5 Final slides returned from students in (A) Question Guided Recall, (B) Guided Assembly and (C) Unguided Assembly. The final slide for the assembly groups was more complex in presentation and challenge than for the Question Guided Recall group.

Individual Question Analysis per Group

Recall Q.	KAMAR	KMOV	KREC	Total Avg/Q
9	5.00	5.00	5.00	5.00
1	**4.81**	4.63	4.80	4.75
7	4.44	4.63	**5.00**	4.69
4	**4.81**	4.44	4.80	4.69
11	4.63	4.44	**4.80**	4.62
15	4.44	4.44	**4.60**	4.50
5	**4.63**	4.26	4.40	4.43
8	4.07	3.89	5.00	4.32
12	3.89	4.26	**4.60**	4.25
2	**4.44**	4.07	4.20	4.24
14	**3.89**	3.89	**4.80**	4.19
6	3.52	3.33	**4.60**	3.82
3	**3.15**	**3.89**	3.80	3.61
13	2.78	3.70	**4.00**	3.49
10	2.96	**3.70**	3.60	3.42
16	2.22	3.15	**4.00**	3.12
Total Avg:	**3.98**	**4.11**	**4.50**	4.20

Transfer Q.	KAMAR	KMOV	KREC	Total Avg/Q
17	3.89	**4.63**	4.60	4.37
18	3.33	3.70	**4.00**	3.68
20	3.52	3.52	3.00	3.35
19	2.41	2.04	**3.40**	2.61
Total Avg:	**3.43**	**3.71**	**4.15**	3.76

Figure 6.6 Individual Question Analysis for Timepoint 1, Experiment 4. A heatmap of results highlights which questions posed most difficulty.

For example, for both assembly groups, the lowest recall score returned was for Q16:

"Which one of the following is a positive regulator of transcription?

and the lowest transfer score returned was for Q19:

"Assume E. coli had a permanent deficiency in cAMP production and could not produce cAMP under any circumstances. How would this affect the E. coli's ability to metabolise lactose?"

For the Question Guided Recall group, the lowest recall score returned was for Q10., a "*Choose the correct statement*," option, and the lowest transfer score was for Q20:

"Scientists discovered a gene located near (but separate to) the Lac Operon in E. coli. They noticed that this gene was transcribed continuously in E. coli. To discover the function of this gene, scientists deleted it. The scientists observed that lots of Lac Z-Y-A mRNA was produced in E. coli with the deleted gene when they were grown on media containing low glucose but no lactose. Based on this new information, what protein is likely to be encoded by the deleted gene?"

All groups scored full marks for Q9:

"Assume that E. coli are actively growing in culture media containing lactose. Predict what will happen if glucose is added to the media."

Another limitation was the non-compliance with the official cut off time for the MCQ which was stated as 3:15 pm. The timestamp for submission as returned by Google Forms showed the majority of the Guided Assembly group submitted results within the specified time. However, a significant number of students from the Unguided Assembly and Question Guided Recall groups did not. To provide a more accurate analysis of the groups, the timestamp results were analysed in 5-minute increments to identify at what point at least one of the groups had returned all results. By 3:25pm, all members of the Guided Assembly group and all except one member of the Unguided Assembly group had submitted results so this was taken to be the new time for analysing results. Beyond that timepoint, it took at least another 10 minutes before the next submissions began to come in from the Question Guided Recall group (from 3:34pm). In total, ten students from the Question Guided Recall group submitted results well beyond the new submission deadline. The latest submission came from the single outlier of the Unguided Assembly group at 3:53 pm. All submissions beyond the 3:25 pm cut-off point were treated as outliers and excluded from analysis.

The lack of compliance to the timing of this study may reflect a time pressure to read through the extra introductory instructions as well as the extra instructions on each slide. This, alongside the addition of a complex final task slide, decreased the learning time for students as the total time for the study session had not been extended. A decision was made to return to the simpler PowerPoint format used in the previous Experiment 3 pilot study for future experiments. In particular, the loss of ten students from the Question Guided Recall group due to non-compliance prompted a rethink of this particular group's design, especially as the mean result from the group (43%) would seem to contradict any particular struggle in comparison to the Unguided Assembly and Guided Assembly groups.

On analysing the data further, it became apparent that many of the questions used for guided recall in the Question Guided Recall PowerPoint were very similar to recall questions used in both Quizzes 1 and 2. With hindsight, it could be argued that this group inadvertently received a pre-run of the MCQ leading to the powerful '*testing effect'* (Roediger & Karpicke, 2006; Brame & Biel, 2015), rather than a notetaking/retrieval practice approach as had been envisioned. However, the Question Guided Recall grade cannot be generalised to other 'test-effect' studies given the lack of time control and the resultant small sample size. For the above

reasons, it was decided to drop the Question Guided Recall design for further use as it was not a suitable or reliable comparison. A non-assembly recall group that could be time-matched to other groups and which would not receive a pre-test advantage required development.

CHAPTER 7

EXPERIMENT 5

7. Two timepoint KLS sub-study comparing a KL assembly technique to a KL static disassembled technique

7.1 Experiment 5 Study Objectives

I. Determine the effectiveness of a KL assembly technique (Unguided Assembly) for learning versus a KL static disassembled technique (Mental Assembly) requiring mental assembly.

II. Develop a suitable marking scheme for multiple choice questions (MCQ) and multi select questions, incorporating both recall and transfer questions.

Table 7.1 Check for Constructive Alignment of Lac Operon Lesson Experiment 5

	Learning Outcome	Teaching & Learning Activities	Assessment
1)	Categorise & order the structural components of the Lac Operon.	Synchronous self-directed learning. PowerPoint lesson & study tasks.	Online MCQs & MSQs completed post-study & 7 days later. Includes recall questions and questions involving transfer of knowledge and understanding to new scenarios.
2)	Connect the function of regulatory molecules with their binding sites & temporal order, in response to sugar type.	As above.	MCQs & MSQs as above.
3)	Relate changes in the presence of glucose & lactose to positive & negative regulation.	As above.	MCQs & MSQs as above.
4)	Predict the outcome for regulation & function of the Lac Operon given a number of novel hypothetical scenarios.	As above.	Transfer questions in MCQ & MSQs will assess whether learning can be applied to novel, hypothetical scenarios.
5)	Complete all aspects of the study as directed by researcher & in compliance with study parameters & ethical standards.	Student completion of Participant Questionnaire & Consent Form. Participation in study & MCQ.	Return of Participant Questionnaire & Consent form. Completion of study, MCQ & MSQs.
6)	Provide insight & guidance on the design, delivery & assessment of the KL lesson & quiz.	Student to relate feedback verbally and/or via email.	Communicate with student in response to feedback & evaluate toward improving KLS.
7 (a)	**Unguided Assembly:** Assemble onscreen diagrams to depict multiple biomolecular scenarios.	Assemble scenarios into a blank space to guide concept development.	MCQ & MSQ. Verbal and written feedback from students on experience.

7 (b)	**Mental Assembly:** Discriminate between correct and incorrectly assembled biomolecular scenarios.	Identify correctly assembled scenarios from incorrect to demonstrate concept comprehension	MCQ & MSQ. Verbal and written feedback from students on experience.

7.2 Stages of Research and Design

Twenty-eight undergraduate science students from a first year biological and chemical science course, comprising multiple scientific disciplines at UCC, participated in the two timepoint KLS study. The first timepoint (T1) of this experiment was conducted on the 9th of April 2021 and the second stage, timepoint 2 (T2), was conducted 7 days later on the 16th of April 2021. Students were recruited as per Experiment 4. Thirty-nine students signed up initially for participation. Their details were coded as per Experiment 4 (see Table 7.3) and further anonymised for randomised group assortment in Excel into the two different study conditions, Unguided Assembly and Mental Assembly (section 3.5, iii).

Table 7.3 Demographic Balance of Groups for Experiment 5

	KAMAR	KSTAT
Male	4	2
Female	10	12
Learning disability	1	2
Levels of Distraction (A rarely : E very easily)		
A	1	
B	2	1
C	5	7
D	2	3
E	3	3

Verbal feedback from students of Experiment 4 stated the use of a mouse was easier for onscreen interactions than using a touchscreen or trackpad. Students who indicated they would use a mouse were re-sorted into the Unguided Assembly group as the use of a trackpad or touchscreen would not affect the Mental Assembly group who did not have onscreen interactions. However, the overall balance between the group for the factors of age, gender, prior science, learning disability, English fluency and level of distraction were prioritised.

7.3 Procedure

The same procedure was followed as per Experiment 4 with minor changes. The Lac Operon lesson video was made more engaging by the addition of a musical intro and outro in Camtasia as outlined in Chapter 3, section 3.4.2. The quiz for T1 retained the same 20 questions in MCQ format. The quiz for T2 was altered from SAQ format to multiselect questions (MSQ), to improve grading efficiency and included 15 questions (see Appendix B, Figure B.2). In addition, the MSQ format would be less prone to ambiguity in answering questions. For example, the SAQ transfer questions used in Experiment 4 tended to receive very short answers, e.g., "*E. coli will die"*, rather than the educated explanation expected, e.g.:

Q13. Assume you created a mutant E. coli where you deleted the Lac Y gene from the E. coli genome. Predict the effect that this deletion would have on E. coli grown on a media in which glucose is absent and lactose is present?

Correct answer: *Lactose cannot enter the cell and therefore the process of transcription cannot proceed as there is no removal of the Lac repressor from the Lac operator in the absence of allolactose – E. coli will die.*

Typically, multiselect questions are marked in three different ways (URL 9):

(i) One point if all correct answers selected or zero if partially correct.

(ii) One point for each correct answer minus the incorrect but lowest mark is zero, i.e., grade cannot go into the negative.

(iii) One point for each correct answer.

A marking scheme was created, this time in Excel, to have a more nuanced correction scheme, as the purpose of T2 was to measure as much learning retention as possible rather than providing a traditional summative grade as such. At the same time, a mechanism for excluding guess answers was necessary without taking punitively from the grade achieved for learning retained. Different questions carried a different mark depending on how many answers were required for that question. For example, the lowest grade of 2 points was given to a question with just one answer option out of five (see (a) below), a grade of 4 points was given to a multi-select question with two required answers out of five (see (b) below) and a grade of 6 was given to a multi-select question requiring three answers out of five (see (c) below):

(a) Which one of the following correctly identifies the structure of the three elements present in DNA located before the three genes of the Lac Operon?
(i) CAP binding site, Lac promoter, Lac operator.

(b) What is the difference between the active state vs. inactive state of the key protein responsible for positive regulation of the Lac Operon? Select ALL that apply.
(i) Active: CAP-cAMP complex recruits RNA polymerase to the Lac promoter = Lac genes transcribed.
(ii) Inactive: CAP-cAMP complex does not form; RNA polymerase is not recruited = no Lac gene transcription.

(c) What role does the Lac repressor play in the Lac Operon? Select ALL that apply.
(i) The Lac repressor sits on the Lac operator located immediately before the Lac genes.
(ii) The Lac repressor physically blocks RNA polymerase from transcribing the Lac genes.
(iii) The Lac repressor is the negative regulator of the Lac operon.

Questions 1-9 of quiz 2 measured recall and questions 10-15 measured transfer learning. Because the transfer questions were more challenging than the recall questions, each transfer question required just one correct answer and was assigned 4 marks. An example of a transfer question is shown below:

Q14. Assume that you genetically manipulated E. coli so that you created an E. coli where you inserted the human insulin gene into the Lac Operon in place of the lac A gene. Predict what would happen if this E. coli was grown on a medium containing lactose but no glucose.
(i) The Lac Z and Y genes will be transcribed and their proteins produced as expected. The insulin gene will also be transcribed to produce the protein for insulin although the insulin gene and protein will play no role in the operation of the Lac operon.

It was foreseen that the structure of some quizzes would be more suitable to grading in increments of 2 or 3 points depending on the total number of multiple choice and/or multi-select questions posed, as well as the total overall number of questions in a quiz. The marking scheme developed by this researcher takes this into account and shows how a quiz can be graded consistently via a partial points reduction system. As there were five answer options or 'parts per question', this reduction is calculated based on how many parts make up a whole, i.e., total points/questions divided by total answers/question (see Table 7.4).

Groups were exactly matched for time by enabling and then turning off the 'response' function in Google Forms at the times specified. A link to MS Teams was given to students in advance to provide an online presence for students if they so

wished and to enable them access immediate troubleshooting advice if necessary, from this researcher. No technical difficulties were reported.

Table 7.4 Marking Scheme for Multi Select Questions

Marking Scheme for Multi Select Questions					
Multi-select Questions with 5 answer options					
Total 6 points/Q	6/5 = 1.2		Total 4 points/Q	4/5 = 0.8	
3 correct answers	2+2+2		2 correct answers	2 + 2	
2 incorrect if ticked	minus 1.2 each		3 incorrect if ticked	minus 0.8 each	
2 + 2 + 2	6	100%	2 + 2	4	100%
2 + 2 + 2- 1.2	4.8	80%	2 + 2 - 0.8	3.2	80%
2 + 2	4	67%	2 + 2 - 1.6	2.4	60%
2 + 2 + 2 - 2.4	3.6	60%	2	2	50%
2 + 2 -1.2	2.8	47%	2 + 2 - 2.4	1.6	40%
2	2	33%	2 - 0.8	1.2	30%
2 + 2 - 2.4	1.6	27%	2 - 1.6	0.4	10%
2 - (1.2) give 1	1.2	20%			
2 - more, give:	0.6	10%			
1 = 17%					
2 = 33%					
4 = 67%					
6 = 100%					
Total 9 points/Q	9/5 = 1.8		Total 6 points/Q	6/5 = 1.2	
3 correct answers	3 + 3 + 3		2 correct answers	3 + 3	
2 incorrect if ticked	minus 1.8 each		3 incorrect if ticked	minus 1.2 each	
3 + 3 + 3	9	100%	3 + 3	6	100%
3 + 3 + 3 - 1.8	7.2	80%	3 + 3 - 1.2	4.8	80%
*3 + 3 + 3 - 3.6	5.4 (0)	60%	*3 + 3 - 2.4	3.6 (0)	60%
3 + 3	6	67%	3	3	50%
3 + 3 - 1.8	4.2	47%	3 - 1.2	1.8	30%
3	3	33%	3 - 2.4	0.6	10%
3 + 3 - 3.6	2.4	27%			
3 -1.8	1.2	13%			
3 - more, give:	0.9	10%			

* Indicates all 5 options ticked in which case, assign a mark of zero

7.4 Methodology of Analysis of Results

Individual quiz responses were corrected automatically in Google Forms as set-up by the researcher and then manually corrected by applying the above grading rubric. Google Form results were downloaded into a .csv file, saved and tidied in Excel and then results extracted for statistical analysis in SPSS (version released 2021). This was the approach taken to analyse all subsequent experiments.

A two-sample *t*-test is the most appropriate statistical test where two independent, normally distributed samples are being compared (Birkett, 2019). A one-tailed *t*-test searches for significance in one direction only (positive or negative) to see if 'X' is better than 'Y' – the answer is yes or no. Because of this, it provides a stronger measure than a two-tailed *t*-test which searchers for significance in both positive and negative directions, thereby halving the significance level to see if 'X' is better or worse than 'Y' or if 'Y' is better or worse than 'X' – the answer is perhaps. As with one-way ANOVAs, the direction of significance from a *t*-test is established using the post hoc Tukey HSD test. The convention for reporting effect size for a *t*-test is the same as that for ANOVAs. However, Eta squared is not used in SPSS for *t*-tests but can be calculated using a simple equation, as sourced from '*SPSS SURVIVAL MANUAL: A step by step guide to data analysis using SPSS'* (p. 243):

The formula for eta squared is as follows:

$$\text{Eta squared} = \frac{t^2}{t^2 + (N1 + N2 - 2)}$$

The guidelines (proposed by Cohen 1988, pp. 284–7) for interpreting this value are:

.01=small effect
.06=moderate effect
.14=large effect

Although not as widely used, a one tailed *t*-test is more powerful than a two-tailed when there is strong reason to believe the direction of the outcome can be reliably predicted (Birkett, 2019). However, with the one-tailed *t*-test, less subjects are required within the samples to reach significance. Thus, the risk is higher for committing a Type I error, i.e., finding significance where there is none. Two-tailed *t*-tests reduce the chance of committing a Type I error but it can be harder to detect statistical significance, thereby increasing the risk of a Type II error, i.e., not finding significance where there is some. The choice to use a one or two-tailed *t*-test:

> "*needs to be decided from within the context of a decision procedure...you need to understand your entire decision procedure rather than simply the statistics*" (Stucchio, 2015).

The effectiveness of interactive learning compared to more passive study approaches is well known (Chi & Wylie, 2014). Hence, it would seem the logical choice here to use a one-tailed *t*-test to see if the interactive Unguided Assembly is better than the passive Mental Assembly. However, the presentation of disassembled scenarios onscreen is not well tested (if at all) and although passive in terms of interaction, the Mental Assembly task demands more focus than simply reviewing pictures on a slide. As the novelty of Mental Assembly lacked prior comparison in research, the most appropriate statistical method was to use a two-sample *t*-test.

7.5 Experiment 5 Results

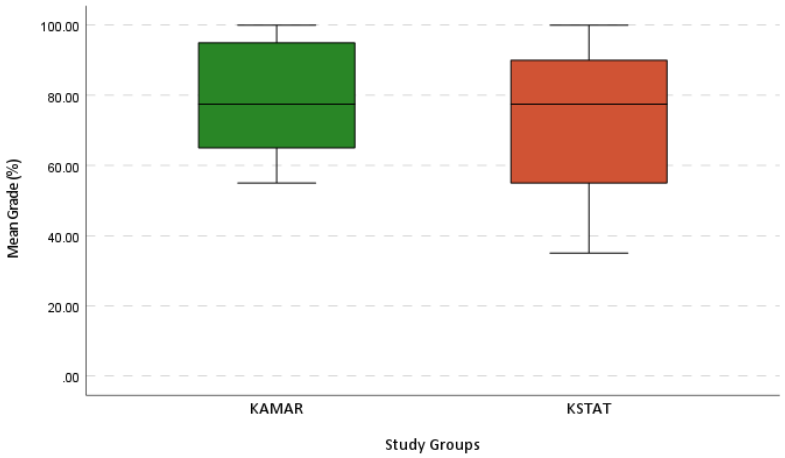
A two-tailed, two-sample t-test assuming equal variances (with significance at $p < 0.5$) and $t(26) = 1.332$, revealed no statistically significant difference between the Unguided Assembly and Mental Assembly groups with respect to age (*M* age = 19.57 years, *SD* 3.16, $p = .194$), or gender ($p = .204$). Nor did the groups differ significantly with respect to academic ability (based on 2021 CAO course entry points $\geq$ 554), English language fluency or learning disability. As this study was run during the second semester of 1st year, most students identified as having taken a prior biological science module although they did not have prior exposure to the topic of the Lac Operon as verified by the lecturer. Eleven participants failed to respond on the day of testing leaving the groups balanced as follows:
Unguided Assembly (*n* 14, *M* age = 19.6 years, *SD* = .7, range 19 – 21 years).
Mental Assembly (*n* 14, *M* age = 21.1 years, *SD* = 4.4, range 19 – 34 years).
The null hypothesis for the independent samples (Unguided Assembly vs. Mental Assembly) stated there was no difference between group means for learning ($H_0: \mu_1 = \mu_2$). The alternative hypothesis stated the group means would differ for learning ($H_A: \mu_1 \neq \mu_2$).

T1: For T1, a two-tailed, independent samples t-test assuming equal variances (with significance at $p < 0.5$) revealed no statistically significant difference for learning between the two study conditions Unguided Assembly (*n* 14, *M* = 78%,

SD = 14.2) and Mental Assembly (*n* 14, *M* = 73%, *SD* = 21.2), *t*(26) = .733, *p* = .47 and we failed to reject the null hypothesis (Figure 7 a).

T2: For T2, a two-tailed independent samples t-test assuming equal variances (with significance at p < 0.5) revealed no statistically significant difference in long-term learning between the two study conditions Unguided Assembly (*n* 13, *M* = 37%, *SD* = 13.9) and Mental Assembly (*n* 12, *M* = 36%, *SD* = 12.4), *t*(23) = .211, *p* = .835. Thus, we failed to reject the null hypothesis (Figure 7 b).

A



B

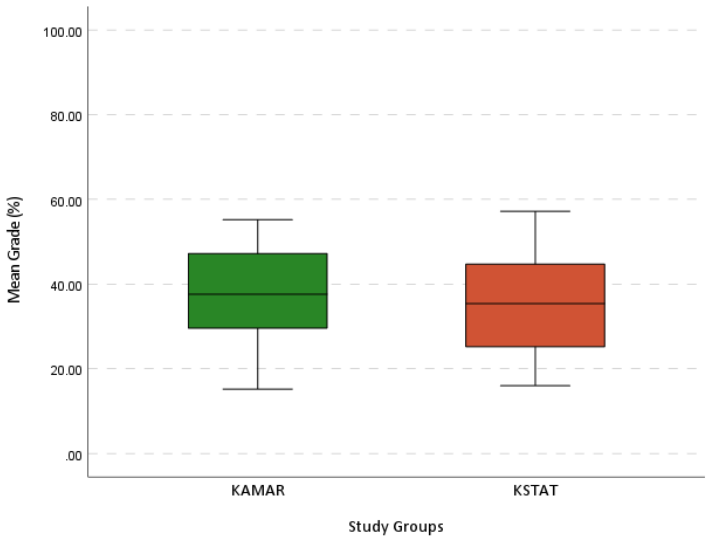


Figure 7 Experiment 5 Comparison of mean grade for Unguided Assembly vs. Mental Assembly. Boxplot (A) results from T1: Unguided Assembly (M = 78%) vs. Mental Assembly (M = 73%). Boxplot (B) Results from T2: Unguided Assembly (M = 37%) vs. Mental Assembly (M = 36%).

7.6 Experiment 5 Discussion

The more nuanced rubric developed to grade the multi-select questions (MSQs) with different grade weightings proved a much faster and easier process of correction in comparison to Experiment 4's SAQ. Its format enabled a single grader to mark the quiz results reliably, without the requirement for a second grader. Small sample sizes limited the power of this study and results must be treated with caution. However, the main purpose of this sub-study was to evaluate the effectiveness of a non-interactive KL approach (Mental Assembly) in comparison to the interactive assembly approach (Unguided Assembly), both of which required recall.

The results are interesting, in that both groups returned high grades in the 70th percentile for T1. Although the Unguided Assembly group performed slightly better with a 5% higher mean grade than the Mental Assembly group, the difference between the mean grades for T2 was just 1%. This indicates an almost equal capacity for long-term learning, with the Mental Assembly appearing more robust than Unguided Assembly in this regard although results within the Mental Assembly group were more variable. The Unguided Assembly group returned less variable results as indicated by the error bars (in Figure 7.1 a). It seems counterintuitive that the Mental Assembly group should perform so well when there was no direct interaction involved, in contrast to the interactive Unguided Assembly group and in contradiction to the ICAP framework (Chi & Wylie, 2014). Yet, if we return to the neuroscience of Chapter 2, studies appear support this outcome.

Electrophysiological studies have demonstrated that imagined movements are comparable to actual movements in activating the primary motor cortex and associated regions of the brain (Leisman et al., 2016). This is believed to be a priming mechanism of the brain to prepare for movement. A typical premotor neuron will start signalling to initiate movement when prompted by external cues, while neurons in the supplementary motor area (SMA) will *"fire most vigorously when the movements are internally generated*" (Hazeltine & Ivry, 2002) that is, when the sequence is from memory. It can be seen that the Mental Assembly requirement to mentally assembly the diagrams is the internal equivalent of the actual assembly used by the Unguided Assembly group. In Chapter 2, the evolutionary development of the brain was linked to the ability to learn kinaesthetically through observation, practice and repetition of tasks. The cerebellum, being one of the oldest structures of the brain in evolutionary terms, is

essential to learning and for controlling the timing and sequential performance of a task (think of playing a violin quickly). It is thought that the cerebellum may apply similar calculations for nonmotor tasks (such as Mental Assembly) to generate an internal representation of the *"temporal relationship between successive events"* (Hazeltine & Ivry, 2002) In other words, the brain is hardwired at many levels to make non-movement carbon copy memories of actual movements, or tasks that might require movement. The similarity between the Unguided Assembly and Mental Assembly groups, despite the different presentation of tasks and modes of engagement, appears to reflect what has been observed in neuroscience studies on learning.

The impact of such a finding, points to an avenue for further research, for students who may have a physical disability which limits or precludes their participation in online interactive learning approaches, not just in the online space but for offline writing or interactive learning approaches that require fine motor skills. Both of these interactive and non-interactive KL approaches provide an alternative means to traditional writing assessments and potentially, reduce the need to rely on support staff such as scribes during exams. Thus, both KL techniques may facilitate progression of learning for users who struggle with the current high reliance on written communication in academia. For users who are physically impaired, the Mental Assembly approach may prove to be a useful tool for equality amongst peers in education, but this requires further research.

This study suggests that testing the Mental Assembly learning approach more concretely amongst users who are physically impaired may be of value; this was not an opportunity that arose for this research. In addition, both the Unguided Assembly and Mental Assembly approaches should be further evaluated by students who are limited in their physical engagement or have a learning disability affecting reading/writing skills. It is hoped that the Mental Assembly approach might be explored further and adopted by other researchers as a comparison condition, to better capture students who might otherwise be precluded from participating in educational research studies. In education practice, the provision of the Mental Assembly approach for these students may better serve to compare their learning progression to those of their peers.

CHAPTER 8

EXPERIMENT 6

8. Two timepoint KLS study of a KL assembly approach vs. a free recall note-taking approach and an active memorisation approach.

8.1 Experiment 6 Study Objectives

I. Determine the effectiveness of a KL assembly technique for learning versus an onscreen, free recall note-taking technique and a memorisation technique modelled on 'cramming' for an exam.

II. Ensure all KLS groups can be time-matched for comparison.

III. Evaluate the effectiveness of the KL lessons for self-directed learning in the absence of the Lac Operon video lesson (which mimicked lecture attendance).

Table 8.1 Check for Constructive Alignment of Lac Operon Lesson Experiment 6

	Learning Outcome	Teaching & Learning Activities	Assessment
1)	Categorise & order the structural components of the Lac Operon.	Synchronous self-directed learning. PowerPoint lesson & study tasks.	Online MCQs & MSQs completed post-study & 7 days later. Includes recall questions and questions involving transfer of knowledge and understanding to new scenarios.
2)	Connect the function of regulatory molecules with their binding sites & temporal order, in response to sugar type.	As above.	MCQs & MSQs as above.
3)	Relate changes in the presence of glucose & lactose to positive & negative regulation.	As above.	MCQs & MSQs as above.
4)	Predict the outcome for regulation & function of the Lac Operon given a number of novel hypothetical scenarios.	As above.	Transfer questions in MCQs & MSQs will assess whether learning can be applied to novel, hypothetical scenarios.
5)	Complete all aspects of the study as directed by researcher & in compliance with study parameters & ethical standards.	Student completion of Participant Questionnaire & Consent Form. Participation in study & MCQ.	Return of Participant Questionnaire & Consent form. Completion of study & MCQs & MSQs.
6)	Provide insight & guidance on the design, delivery & assessment of the KL lesson & quiz.	Student to relate feedback verbally and/or via email.	Communicate with student in response to feedback & evaluate toward improving KLS.

7 (a)	**Unguided Assembly:** Assemble onscreen diagrams to depict multiple biomolecular scenarios.	Assemble scenarios into a blank space to guide concept development.	MCQs & MSQs. Verbal and written feedback from students on experience.
7 (b)	**Free Recall:** Rewrite lesson in own words using free recall of learned content.	Rewrite lesson into blank box onscreen, recalling lesson in own words.	MCQ, MSQs & feedback as above.
7 (c)	**Neutral**: Memorise key concepts without the use of additional learning aids.	Actively memorise the lesson.	MCQ, MSQs & feedback as above.

8.2 Stages of Research and Design

This study was conducted in two parts due to student availability and to maximise student participation. Part one of this study was run in November 2021 and involved 84 students from 1st year undergraduate medicine (UCC). Part two was run in February 2022 and involved 33 science students from the 1st year undergraduate biological and chemical sciences programme (UCC). Sorting details for both groups are outlined separately but results will be presented from both student groups jointly, in compliance with how the study procedure was outlined to students.

Part I:

Eighty-four students from the 1st year undergraduate medicine subject pool at UCC participated in the two timepoint KLS study. One hundred and five students signed up initially and were randomly assigned across three groups, Unguided Assembly, Free Recall, Neutral (section 3.5, vi) in Excel and their details coded as per Experiments 4 & 5 (Table 8.2). Some students did not identify a level of distraction.

Table 8.2 Demographic Balance of Groups for Experiment 6, Part I

	KAMAR	KFREE	KNEUT
Male	12	12	9
Female	16	17	18
No gender ID	1		
Learning disability	1	2	1
Prior science	6	5	5
Touchscreen/trackpad	19	19	19
Levels of Distraction (A rarely : E very easily)			
A	2	2	2
B	4	5	7
C	6	9	7
D	10	7	6
E	5	6	5

Twenty-two participants failed to respond on the day of testing leaving the groups balanced as follows: *Unguided Assembly* (*n* 29), *Free Recall* (*n* 29), *Neutral* (*n* 27).

Part II:

Thirty-three students from the 1st year undergraduate science subject pool at UCC participated in the two timepoint KLS study. Fifty-one students signed up initially and were randomly assigned across the three groups (Unguided Assembly, Free Recall, Neutral) in Excel and their details coded as per part 1. The first stage of the study (T1), was conducted on the 8th of Feb 2022 and the second stage (T2), was conducted 7 days later on the 15th of Feb 2022. The majority of students indicated they had taken a prior science module at third level as this experiment was conducted during semester 2 of 1st year. Eleven participants failed to respond on the day of testing leaving the groups balanced as per Table 8.3.

Table 8.3 Demographic Balance of Groups for Experiment 6, Part II

	KAMAR	KFREE	KNEUT
n	*11*	*9*	*13*
Male	4	3	3
Female	7	6	10
English 2nd language	2	2	1
Learning disability			
Colour blind		1	
Levels of Distraction (A rarely : E very easily)			
A			
B	3	3	4
C	4	4	5
D	4	5	2
E		3	1

8.3 Procedure

The same procedure as per Experiment 5 study set-up and quiz format was followed. The Lac Operon video lesson was dropped to ascertain whether the KL lessons alone were sufficient to aid learning. The Free Recall condition replaced the Question Guided Recall condition used previously in Experiment 4. To recap, this condition required students to type as much information as they could remember from the previous lesson slide into a blank box, using their own words.

8.4 Methodology of Analysis of Results

As per Experiment 5.

8.5 Results

For Part 1 participants: One way-ANOVAS revealed no statistically significant difference between the Unguided Assembly, Free Recall and Neutral groups for age (M = 18.1 yrs, SD = 1.8, p = .580), or gender (p = .354). Nor did the groups differ significantly with respect to academic ability (based on 2021 CAO course entry points range 738 - 781) or English language fluency. Nor did Part 2 participants differ with respect to academic ability (based on 2021 CAO course entry points 555), age (M = 20.2, SD = 2.3), gender and English language fluency. One person in the Neutral group did not identify a level of distraction. Graphs for both timepoints appear under Figure 8.

T1:

The null hypothesis for the independent samples (Unguided Assembly vs. Free Recall vs. Neutral) stated there was no difference between group means for learning (H_0:$\mu_1=\mu_2=\mu_3$). The alternative hypothesis stated that at least one pair of means would differ from each other for learning (H_A: $\mu_i \neq \mu_j$, for at least one pair of groups where i, j = 1, 2, 3 and $i \neq j$).

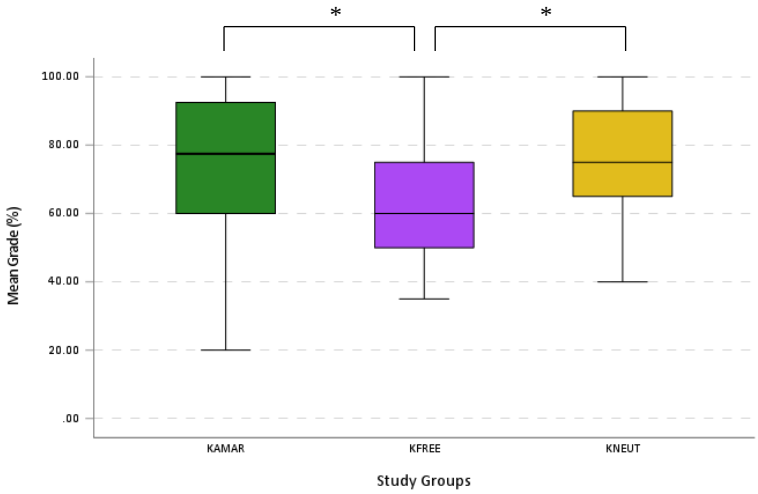
A one-way between groups ANOVA (with α significant at $p < 0.5$) was conducted to compare the effect on learning of the KLS study condition Unguided Assembly, the non-KLS study condition of Neutral and the study condition Free Recall which is based on proven note-taking strategies using a computer (Bui, Myerson, & Hale, 2013; Chi & Wylie, 2014). A statistically significant effect for learning was revealed, [$F(2,113) = 4.629$, p = .012] with a moderate effect size (η^2 = .076).

Post hoc comparisons using the Tukey HSD test indicated the mean score for the Neutral condition (n 38, M = 75, SD = 16.66) was significantly higher than the Free Recall condition (n 38, M = 64, SD = 16.81), p = .021, 95% CI = [1.39, 20.98], leading to rejection of the null hypothesis. The Unguided Assembly condition (n 40, M = 74, SD = 20.10) also returned higher results than the Free Recall condition which were statistically significant (p = .031) 95% CI = [.76, 20.10], leading to rejection of the null hypothesis. No statistically significant difference was found between the Unguided Assembly and Neutral conditions (p = .981) and we failed to reject the null hypothesis.

T2:

A one-way between groups ANOVA (with α significant at $p < 0.5$) revealed no statistically significant difference in long-term learning retention across the three different study conditions Unguided Assembly (*n* 36, *M* = 54%, *SD* = 24.23), Free Recall (*n* 37, *M* = 47%, *SD* = 119.58) and Neutral (*n* 35, *M* = 52%, *SD* = 19.59); $F(2,105) = 1.229$, $p = .297$. Despite a 7% grade difference between Unguided Assembly and Free Recall, we failed to reject the null hypothesis for all conditions.

A



B

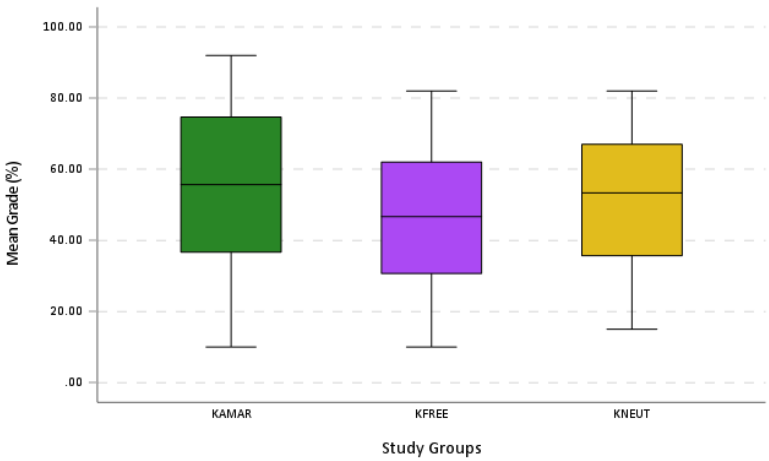


Figure 8 Experiment 6 Comparison of mean grade for Unguided Assembly vs. Free Recall vs Neutral. Boxplot (A) results from T1: Unguided Assembly (M = 74%) vs. Free Recall (M = 64%) vs. Neutral (M = 75%). Boxplot (B) results from T2: Unguided Assembly (M = 54%) vs. Free Recall (M = 47%) vs. Neutral (M = 52%).

8.6 Experiment 6 Discussion

From the previous experiments, Unguided Assembly appears to be more robust for long-term learning retention over time compared to groups which initially outperformed Unguided Assembly in T1 tests. This again proved to be the case for this experiment, although the difference was marginal in comparison to the Neutral group (In T1, Unguided Assembly 1% < Neutral and in T2, Unguided Assembly 2% > Neutral). The introduction of more dispersed timepoints for testing would reveal how persistent any learning retention would remain over a longer timeframe.

As discussed in Chapter 2, the ICAP framework (Chi & Wylie, 2014) describes a hierarchy of behaviours which are correlated to student engagement and learning:

> *"Interactive behaviors subsume constructive, and constructive behaviors subsume active, and active behaviors subsume passive" (p. 225).*

Under the ICAP framework, taking notes is described as a *constructive* approach. The method used to take notes influences how effective that note-taking will be (Chi & Wylie, 2014). This includes whether, (a) the instructions given to students make it an "active, constructive, or interactive" task and (b) what condition the note-taking is compared to, e.g., was constructive note-taking compared to another constructive condition, active or passive? Therefore, in line with the hierarchy of the ICAP framework, the expectation is that the Unguided Assembly interactive approach would outperform the Free Recall constructive and both would outperform the Neutral passive approach. Given the evidence from research that taking free-form notes on a computer (Trafton & Trickett, 2001; Bui et al., 2012) and self-explaining text (Bauer & Koedinger, 2007 as cited in Chi & Wylie, 2014; Kogl et al., 2016) is more effective than passive approaches such as re-reading text, it was expected that the Free Recall group would outperform the Neutral group. This was not the case.

Perhaps the difference is that the Neutral group were instructed to memorise the text instead of simply re-reading the lesson text. It may be that the memorisation aspect is the more successful element for learning in Karpicke's retrieval-practice studies (2011, 2017, 2020) rather than the repetition element, despite memorisation being considered a lower order cognitive skill (LOCS) (Crowe et al., 2008). In fact, when repetition was separated from memorisation in a study in which students repeated sentences onscreen to learn the circulatory system, their learning was less

than students who were required to explain the sentences in their own words (O'Reilly et al., 1998). Therefore, memorisation should not be viewed as a passive approach in the sense of being an LOCS. The act of committing something to memory should more suitably be recognised as an active mental process and thus, a higher order cognitive skill, as exemplified by the Neutral group in this experiment and by the Mental Assembly group in the previous experiment 5.

The Unguided Assembly group results correspond with the predicted outcome of the ICAP taxonomy and in line with the researcher's expectations, i.e., an interactive approach outperformed a constructive approach. However, it was not expected that Neutral would be on a par with Unguided Assembly (a 1% grade difference) for T1. In the broader context of how students' study for exams, these results provide some validity for the phenomenon of 'cramming' or intense, focused memorisation for learning under a time pressure. Feedback from students indicated the Hawthorne effect may have been relevant toward maintaining more focus for effective memorisation, despite attempts to mitigate this by keeping students unaware of the expectations for the conditions they were assigned to in advance.

8.7 Limitations of the Study

Overall, the group sample sizes were robust for both timepoints. Cluster random sampling was used but this method can fail to take into account different variables that can arise between experiments when they are conducted on different dates and in different places, e.g., environmental surrounds for one set of students may be more favourable than another, different teachers and so forth. Hence, results are reported with the caveat that two different student cohorts were used. Conversely, this is also an advantage of the KLS as students participated online from wherever they chose and on their own digital devices. Thus, it is unlikely the difference in dates or in belonging to a particular student cohort would have had any impact. In addition, students participated independently and used self-directed learning to complete the study so it is unlikely that clustering would have skewed any results.

Studies such as this require voluntary human participation and it can be a struggle to achieve all desired parameters. For example, hosting different student cohorts in a single study session was not possible due to differing education commitments. This reflects the realistic hurdles that naturally arise within education,

whether online or in classrooms. Therefore, it was necessary to separate this experiment into two different parts. Difficulty in recruiting a large enough sample of subject relevant volunteers at undergraduate level might explain why science education researchers have tended to use simpler, shorter science topics as discussed in Chapter 3. Nonetheless, using such a simplified approach cannot reflect science learning accurately.

The KLS framework offers a more unified approach in providing practical steps and guidelines as outlined in detail in Chapter 3, for designing more complex science lessons amenable for both research, education and assessment. The next step of testing the KLS framework was to evaluate its scalability and expandability. The framework's guidelines were followed to create a research lesson on the topic of DNA transcription and translation, for dissemination amongst local and national secondary schools in Ireland and is discussed in Experiment 9.

CHAPTER 9

EXPERIMENT 7

9. Assessing the scalability and expandability of the KLS in collaboration with a selection of Irish secondary schools

9.1 Experiment 7 Study Objectives

I. *Compare all optimised KL lessons developed to date (excluding* Question Guided Recall*) to determine their effectiveness for learning at second-level, using a DNA Research Lesson.*

II. *Instruct secondary school teachers on the correct application of KLS in a classroom setting.*

III. *Assess the practicality of delivering the KLS remotely to a third party.*

Table 9 Check for Constructive Alignment of the DNA Research Lesson

	Learning Outcome	Teaching & Learning Activities	Assessment
1)	Categorise & differentiate between DNA, mRNA, genes, amino acids & proteins.	Synchronous self-directed learning. PowerPoint lesson & study tasks.	Measure learning online MCQ & MSQ completed post-study & 7 days later. Includes recall questions and questions involving transfer of knowledge and understanding to new scenarios.
2)	Differentiate between transcription and translation.	As above.	MCQs & MSQs as above.
3)	Match nucleic acid base pairs, differentiate between bonds & DNA/mRNA sequences.	As above.	MCQs & MSQs as above.
4)	Connect the function & temporal order of regulatory molecules to DNA transcription & translation, including RNA polymerase, ribosomes & tRNAs.	As above.	MCQs & MSQs as above.
5)	Predict the outcome for DNA transcription & translation given a variety of novel, hypothetical scenarios.	As above.	Transfer questions in MCQs & MSQs will assess whether learning can be applied to novel, hypothetical scenarios.
6)	Complete all aspects of the study as directed & in compliance with study parameters & ethical standards.	School, student & parental consent & completion of Participant Information forms. Participation in study & MCQs.	Return of all related forms. Teacher feedback. Completion of study & MCQs & MSQs.
7)	Provide insight & guidance on the design, third-party delivery & assessment of the KL lesson & quizzes in a secondary school.	Teachers to relate feedback verbally by phone/Teams/email.	Communicate with teachers in response to feedback & evaluate toward improving KLS.

8(a)	**Unguided Assembly:** Assemble onscreen diagrams to depict multiple biomolecular scenarios.	Assemble scenarios into a blank space to guide concept development.	MCQs & MSQs. Verbal and written feedback from teachers on experience.
8(b)	**Guided Assembly:** Assemble onscreen diagrams to depict multiple biomolecular scenarios.	Assemble scenarios over neutral pre-assembled diagrams to guide concept development.	MCQs, MSQs & feedback as above.
8(c)	**Free Recall:** Rewrite lesson in own words by freely recalling the lesson content.	Rewrite lesson into blank box onscreen, recalling lesson in own words.	MCQs, MSQs & feedback as above.
8(d)	**Mental Assembly:** Discriminate between correct and incorrectly assembled biomolecular scenarios.	Identify correctly assembled scenarios from incorrect to demonstrate concept comprehension	MCQs, MSQs & feedback as above.
8(e)	**Neutral**: Memorise key concepts without the use of additional learning aids.	Actively memorise the lesson.	MCQs, MSQs & feedback as above.

9.2 Stages of Research and Design

Secondary schools at local and national level in Ireland were approached via phone and email to invite participation in the KLS study. Teachers were recruited to facilitate running the KLS study as briefly outlined in Chapter 3, section 3.4.3. Cohen et al., (2007) pay particular attention to school-based research, with the advice that researchers must consider ethics at all stages:

> *"No more so than at the stage of access and acceptance, where appropriateness of the topic, design, methods, guarantees of confidentiality, analysis and dissemination of findings must be negotiated with relative openness, sensitivity, honesty, accuracy and scientific impartiality" (p.59).*

Cohen's ten steps for negotiating access to secondary schools was applied as follows (adapted from Cohen et al., 2007, p. 59):

Step 1: Formally request permission to carry out your research.

Step 2: Speak to the people who will be asked to cooperate.

Step 3: Submit the project outline to the principal of the school.

Step 4: Define what you mean by anonymity and confidentiality.

Step 5: Decide what aspects of the research will be shared with participants.

Step 6: Inform participants about what will be done with their information.

Step 7: Outline the conditions under which the study will be conducted.

Step 8: Be honest about the purpose of the study and conditions of research.

Step 9: Remember that people who agree are doing you a favour.

Step 10: Never assume 'it will be alright.' Pay attention to negotiations.

To help teachers understand fully what their role for this study would entail, a link to a short 'Teacher's Instructions' video was included with invitational emails (view through the link: https://www.screencast.com/t/iotiPTtSfX). Three local secondary school teachers who were not participating in this KLS experiment agreed to test-run the delivery and implementation of the study on school computers in advance of sending out PowerPoint lesson packs to each school. Feedback was positive and lead to some important tweaks, such as providing the option to deliver videos as MP4 attachments in emails, as well as via online links.

These three teachers were thanked and given a small token gift in appreciation for their time. Participating teachers were advised the entire study session was designed for delivery in a single class session (typically 45 mins at second-level) but that a double class would ensure no undue pressure for teachers or students should any technical difficulties arise. The timing of the study session was set out as follows:

*"(8 min) Video lesson on DNA transcription and translation – teacher plays this to the class (*view through the link: *https://www.screencast.com/t/s0I86h4G6).*
(25 min) PowerPoint lesson and study task completion – students complete independently on laptops/chrome books/desktop computers (whichever the school prefers to use).
(10 min) Google Form Quiz – results are returned automatically to researchers."

In facilitating the study, teachers were advised they would not be required to teach or grade the topic, as the '*DNA Research Lesson'* is set-up in PowerPoint for self-directed learning by the student. The student cohort of interest were those from Transition Year and/or Senior Cycle classes (typically 15 – 18 yrs) and it was stated that students did not have to be taking science as a Leaving Certificate subject to participate (see Appendix C, Figure C.1). Teachers who agreed to run the study were emailed a zipped folder attachment titled 'Lesson Pack,' containing the following:

1) Participant information sheet for circulation to parents and students
2) Parental consent/student assent forms (in both paper and digital formats)
3) Excel sheet with study codes to assign to students to protect their anonymity
4) Study PowerPoints

Parental/guardian consent forms were provided for students under the age of 18 and assent forms for students over 18, in both paper and digital format, to accommodate

school preference and in compliance with the requirements of the Social Research Ethics Committee (SREC) in UCC. Appendix C includes information and consent forms from the lesson pack (Figure C.2). Teachers were informed that all students who volunteered would be issued with an anonymous code and participating schools would also remain anonymous. Non-participating students present in the classroom were provided with an identical copy of the lesson, minus study aids and without the requirement to participate in any post-test quizzes, as advised by the SREC.

The lesson pack was numbered as 'School 1 lesson pack', 'School 2 lesson pack,' etc., according to the order in which schools signed up. The excel sheet in each pack contained codes unique to the school lesson pack allowing a level of traceability for troubleshooting issues. A link to a second 10-min multi-select MCQ '*Quiz 2'* was emailed to teachers to run with their students 7 days after the initial study session, the results of which were used to measure long-term learning retention. Teachers were asked not to cover any aspect of the DNA research lesson with their students again in between Quiz 1 and Quiz 2. Secondary school students were reminded that their teachers would not be aware of any individual student's performance as results returned automatically to the researchers. Because a study code was entered on quiz results, the researchers equally would not be able to identify any student with their result.

9.3 Procedure

This study was conducted using a cluster random sampling approach. Results from all schools will be presented jointly, in compliance with how the study procedure was outlined to participating schools and as per ethical approval. Figure 9.1 shows an infographic outlining the basic protocol used for running this study. Twenty-one secondary schools in total were contacted locally and nationally. Those who did not respond to emails received a follow-up phone call. Five schools facilitated the study but one of these was subsequently dropped from the data analysis when it emerged (through contact with the teacher) that the interactive Unguided Assembly (Oranges) condition was not implemented, i.e., the teacher had advised his students not to interact with onscreen elements in case they would change the layout of the lesson. This meant there was no comparison possible.

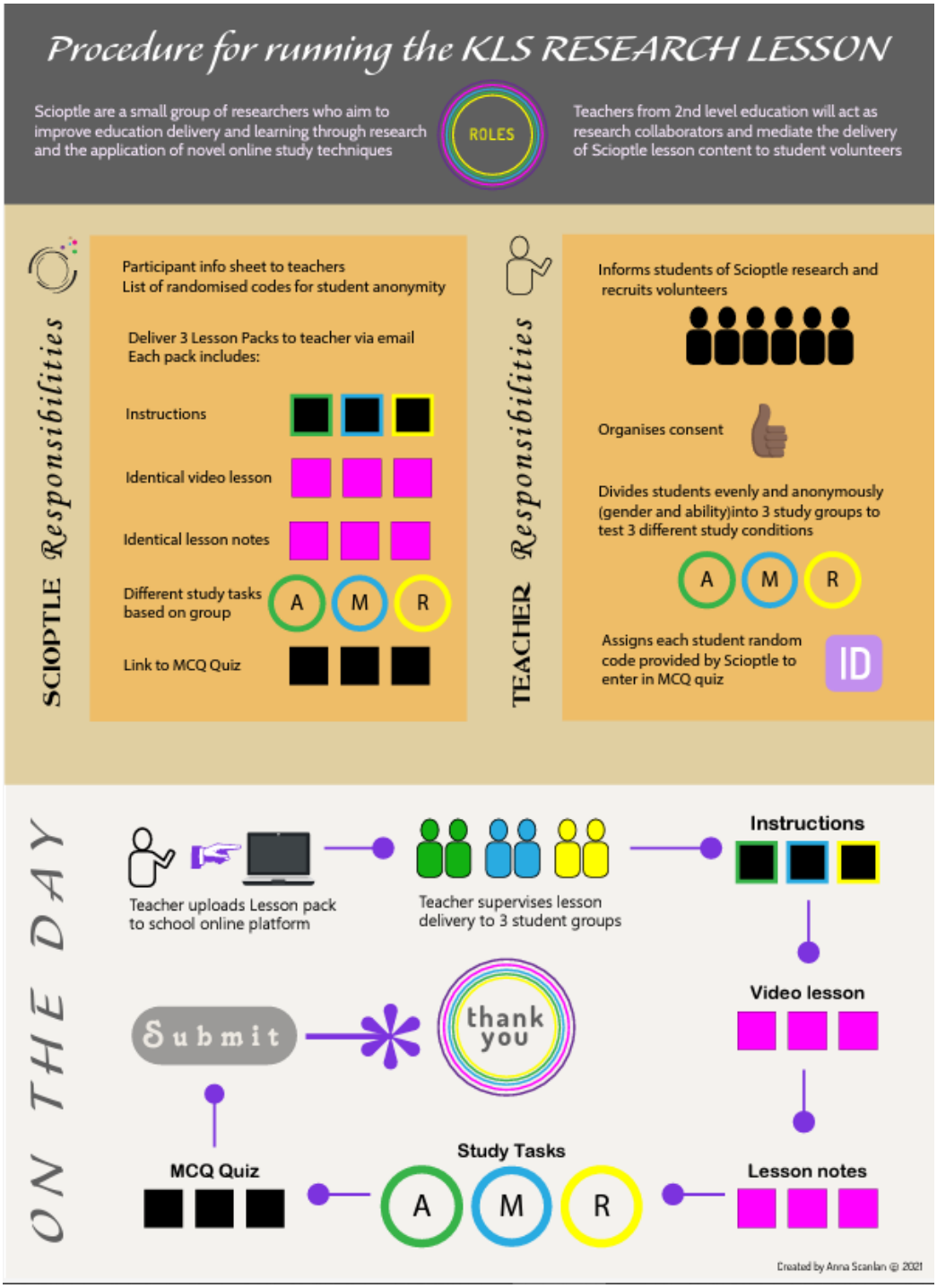


Figure 9.1 Infographic for Secondary Schools. The overall flow of implementing the KLS study in secondary schools was outlined. This infographic was included in the secondary school lesson pack.

The teacher admitted he had not read the instructions for the study as felt there was too much information in the Participant Information Form. However, it was necessary for the approval of this study to follow the detailed template provided by the SREC, UCC. Three other teachers contacted this researcher by phone and Zoom

meetings to ensure they were following all instructions correctly. Once it was confirmed that they were, they were happy to proceed.

On the day of T1 testing, the teacher assigned each student to one of the study conditions and provided students with their unique study code. The teacher played the lesson video to the class, immediately after which students followed the instructions in the PowerPoint to complete their PowerPoints and tasks independently. The teacher remained in class to supervise only and no teaching was involved. The teacher activated the MCQ supplied by this researcher in Google Forms at the end of the learning session (as outlined already) and students proceeded through the online MCQ independently which was embedded as a link in the final slide of the lesson (Appendix C, Figure C.3). The quiz was closed for access after the required time set out by the study parameters and only the researchers were able to view quiz responses from this point on. Therefore, the teacher was not aware of student results and had no part in marking the quiz. Seven days later (T2), the teacher activated Quiz 2 and the students completed the MSQ independently up until the quiz was deactivated by the teacher as per the appointed time (Appendix C, Figure C.4).

The students' unique study code was entered into the Google Form Quiz 1 to help this researcher identify the group from which results were returned; individual students remained unidentifiable throughout. The results from individual schools will not be shared in compliance with the ethics stated for this study. However, this researcher has committed to sharing which condition performed best with secondary schools on completion of this thesis.

9.4 Methodology of Analysis of Results

Similar to the previous experiments, responses were downloaded from both Google Form quizzes as .csv files and converted into .xlsx files for sorting in Excel according to when results returned from the various secondary schools. Once all secondary schools had completed their participation, results from the various study conditions were grouped together and transferred to SPSS for analysis.

9.5 Results

Qualitative feedback was gathered from three secondary school teachers prior to approaching secondary schools. They kindly provided the following insights:

Teacher 1:

"I got it working on Screencast but only through Chrome.. Explorer or Edge not working for me but that might only be a problem with this laptop. The list of instructions on the video were very clear. I would be happy to prepare for and teach those lessons if needed. The video was very clear and easy to follow. The only worry I would have is access to IT and whiteboards / projectors can vary a lot between schools and within schools. Ye probably have that worked out and discussed already.

The PPTs were easy to follow. I didn't follow the link to the google form in case it sent a partial completed response or anything like that. I really like the format of the Orange presentation. The only thing I could say was that the lower half of slides 8 and 10 on Apples PPT was very faint and difficult to read on the laptop. If that went up on a bigger screen with sunlight etc it would be very difficult to read.

The rest looked very impressive even if I didn't have a clue about DNA biology. The slides were definitely some of the best I've seen and not too print and text heavy. There is a push on in schools to be implementing Assessment for Learning and the whole thing definitely fits in with that. Its right on topic too with most teachers now working hybrid models with some online and offline content. We all got our materials ready to go online for lockdown and your approach compliments the new way we all have to work now. Most teachers never went back to 100% offline teaching. Fair play that's very impressive looking."

Teachers 2 & 3:

"We have gone through the files that you sent and it all looks great. There is no doubt that it is a serious body of work. We didn't come up with much but hopefully the message below is clear enough.

1. Invitation to the School Principal- This explains everything quite well and was our starting point. I was a little lost on the explanation of the codes etc but I'm sure it would more sense when you are actually doing it. I def think the screencast is worth sending- it played perfectly and gave a very clear picture of what is required and how it would be delivered. Again, I was a bit wary when it came to explaining the codes- if it was my class I would much prefer to divide them up myself most likely

with the same results. When it came to the excel sheets etc I would be worried it could look like more work than it actually is! Then again (J) didn't have the same issue so it could be just a case of my very unscientific mind overthinking it:-)
2 .We didn't seem to have the 8-minute video that the teacher plays so couldn't test that. All of the PowerPoints opened and played no problem and while I couldn't comment on content, the tasks all seemed clear and the slides easy to follow and interesting- though I would be concerned about losing some of the lower ability students even at Leaving Cert. The link to the MCQ test didn't work but I am assuming that it is not gone live yet.
3. We tried it on the windows laptop, chrome books and school computers without any problems opening or running it.
4. Overall it looks like a really interesting investigation- and def anything that improves student engagement has to be a big plus."

T1:

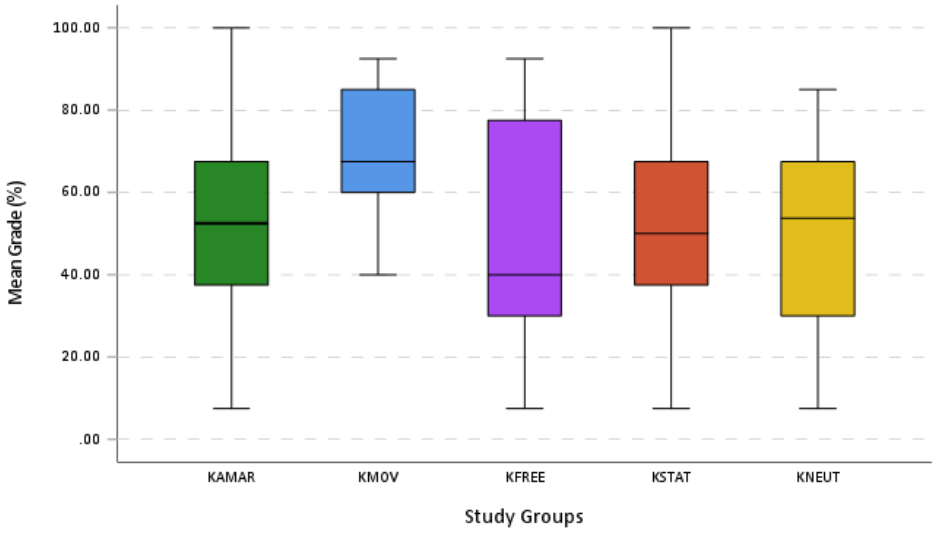
The null hypothesis for the independent samples (Unguided Assembly vs. Guided Assembly vs. Free Recall vs. Mental Assembly vs. Neutral) *stated* there was no difference between group means for learning (H_0:$\mu_1 = \mu_2 = \mu_3 = \mu_4$). The alternative hypothesis stated that at least one pair of means would differ from each other for learning (H_A: $\mu_i \neq \mu_j$, for at least one pair of groups where i, j = 1, 2, 3, 4 and $i \neq j$).

Results returned were as follows: Unguided Assembly (*n 42*, *M* = 52%); Guided Assembly (*n* 7, *M* = 70%); Free Recall (*n* 21, *M* = 46%); Mental Assembly (*n* 30, *M* = 53%); Neutral (*n* 30, *M* = 50%). A one-way between groups ANOVA (with α significant at $p < 0.5$) did not reveal a statistically significant difference in learning between the study conditions [$F(4,125) = 1.41$, $p = .231$] and we failed to reject the null hypothesis (see Figure 9.2 a).

T2:

A one-way between groups ANOVA (with α significant at $p < 0.5$) revealed a statistically significant difference between the groups with respect to learning [$F(4, 88) = 2.668$, $p = .037$]. Post hoc comparisons using the Tukey HSD test indicated the higher mean score for the Guided Assembly condition (*n* 7, *M* = 52) was marginally significant compared to that of the Unguided Assembly condition (*n* 30, *M* = 30), $p = .058$, 95% CI = [-4.8, 43.78] (see Figure 9.2 b).

A



B

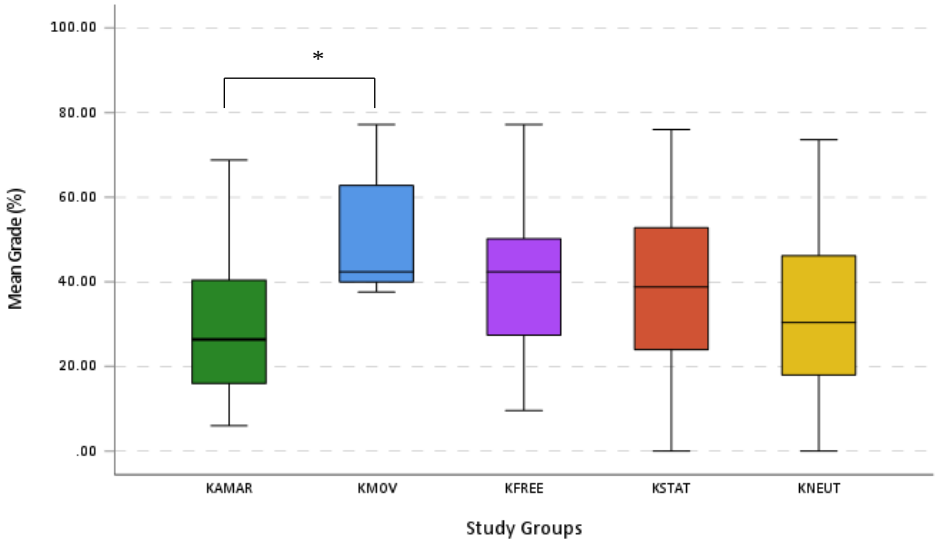


Figure 9.2 Experiment 7 Comparison of Secondary School Study Results. Boxplot (A) results from T1: Unguided Assembly (M = 52%) vs. Guided Assembly (M = 70%) vs. Free Recall (M = 46%) vs. Mental Assembly (M = 53%) vs. Neutral (M = 50%). Boxplot (B) results from T2: Unguided Assembly (M = 30%) vs. Guided Assembly (M = 52%) vs. Free Recall (M = 43%) vs. Mental Assembly (M = 40%) vs. Neutral (M = 37%).

9.6 Experiment 7 Discussion

Despite the marginal significance of the Guided Assembly group for learning over the Unguided Assembly group, this result cannot be considered reliable due to the highly uneven cell size of the Guided Assembly group which likely skewed results positively in comparison to all other groups (see Figure 9.2). The Guided

Assembly group returned the highest grades for both timepoints which is the first instance of this occurring. Again, not much weight can be attached to the finding given the small sample size for this group.

Similar to the previous Experiment 7, Unguided Assembly returned a higher grade than Free Recall (6% grade difference) for T1 but also, a marginally better grade (2%) than Neutral. This was reversed for T2, in which all groups unexpectedly outperformed Unguided Assembly. It is plausible that the large drop in sample size from the Unguided Assembly group between T1 (*n* 42) and T2 (*n* 30) negatively skewed results as this outcome is different to the pattern seen in previous experiments with the Unguided Assembly group. Similar to T2 in Experiment 5, there was just a 1% grade difference between Unguided Assembly and Mental Assembly in T1, which is remarkably consistent and interesting in terms of potential to act as an alternative to more interactive approaches, across different knowledge levels and age cohorts.

One of the guiding criteria for developing the KLS framework was to enable a format that was expandable for use in different settings and for different knowledge levels. This proved possible through the realistic implementation of the '*KLS DNA Research Lesson'* in classrooms at second level for independent, yet synchronous use within schools in a highly repeatable manner. Students were able to cover the topic for which they had no prior knowledge, as confirmed by teachers running the study, in under 30 mins.

9.7 Limitations of the Study

Much interest in participating was expressed by the many schools approached but teachers are time-poor and found it difficult to commit to running the study or for slotting the necessary time required into the school timetable. Compounding this difficulty was that recruitment of secondary schools took place during a high infection stage of the Covid-19 pandemic (Sept'21 – Feb '22). At that time, it was not known when classes might fully return to normal or whether government health-guidelines would become stricter. The first school who actively participated did so in Dec '21, with the final school participating in Feb'22 and there remained high levels of staff and student absenteeism at that time. In all, half the schools who agreed to participate withdrew, with more expressing an interest in doing the study at a future date should education return to pre-pandemic conditions.

Feedback was positive from the schools that participated. One teacher requested if his school could continue to use the PowerPoints and lesson video and this researcher was happy to oblige in thanks for their participation. The use of unique codes per school worked especially well in maintaining student anonymity while still enabling a level of traceability. For example, one teacher got in touch prior to Quiz 2 to say some of his students in the Grapes group could not remember the codes they had used in Quiz 1, and he was uncertain of the codes assigned. By going into the Quiz 1 Google Form and locating codes which matched other group codes from the lesson pack sent to him, the original codes could be reassigned to the teacher, while still maintaining the complete anonymity of the students. Maintaining anonymity in grading is an especially hot-topic issue in Irish education and this study, although comparatively small, reveals a way to achieve that anonymity at a local level.

As of early 2023, education has largely returned to pre-pandemic conditions but it is difficult to predict when the KLS might be run amongst schools again for better evaluation of its effectiveness for learning at second level. Significant groundwork has been laid and technical problems overcome to facilitate rapid dissemination within schools when that time arises.

CHAPTER 10

EXPERIMENT 8

10. Sub-study challenging the KLS with a short, intensely complex science lesson amongst postgraduates from multiple disciplines

10.1 Experiment 8 Study Objectives

I. *Explore whether KL techniques are expandable to the highest levels of academia amongst post-graduates for remote, self-directed learning of an advanced science topic on Salmonella virulence factors.*

II. *Investigate whether KL techniques can support learning in the absence of background information to scaffold understanding for the topic.*

III. *Challenge the effectiveness of the KLS with the intensely complex, short science text for learning in under 15 minutes.*

IV. *Compare learning of the advanced science topic using the KLS amongst students heavily invested in science and those with no science whatsoever.*

Table 10 Check for Constructive Alignment of the Salmonella Science Taster Lesson

	Learning Outcome	Teaching & Learning Activities	Assessment
1)	Identify the structural components of Salmonella.	Asynchronous, self-directed learning. PowerPoint lesson & study tasks.	Online MCQ & MSQs completed post-study & 7 days later. Includes recall questions and questions involving transfer of knowledge and understanding to new scenarios.
2)	Differentiate between invasion genes and the proteins they encode.	As above.	MCQs & MSQs as above.
3)	Explain the infection mechanism employed by Salmonella.	As above.	MCQs & MSQs as above.
4)	Predict the outcome for Salmonella pathogenicity & disease given a variety of novel, hypothetical scenarios.	As above.	Transfer questions in MCQs & MSQs will assess whether learning can be applied to novel, hypothetical scenarios.
5)	Complete all aspects of the study as directed by researchers & in compliance with study parameters & ethical standards.	Student completion of Participant Questionnaire & Consent Form. Participation in study & both MCQs.	Return of Participant Questionnaire & Consent form. Completion of study & both MCQs within allotted time.

6 (a)	**Unguided Assembly:** Assemble onscreen diagrams to depict multiple biomolecular scenarios.	Assemble scenarios into a blank space to guide concept development.	MCQs & MSQs as above.
6 (b)	**Guided Assembly::** Assemble onscreen diagrams to depict multiple biomolecular scenarios.	Assemble scenarios over neutral pre-assembled diagrams to guide concept development.	MCQs & MSQs as above.
6 (c)	**Free Recall:** Rewrite lesson in own words by freely recalling the lesson content.	Rewrite lesson into blank box onscreen, recalling lesson in own words.	MCQs & MSQs as above.
6 (e)	**Neutral**: Memorise key concepts without the use of additional learning aids.	Actively memorise the lesson.	MCQs as above.

10.2 Stages of research and design

A between-groups design was used for comparing the four independent learning conditions Unguided Assembly, Guided Assembly, Free Recall and Neutral using the 'Science Taster' lesson on *Salmonella* virulence factors. Both science and non-science postgraduate students were invited to test a short, advanced and detailed microbiology lesson <300 words on invasion factors in *Salmonella*. For those of a science background, the use of a science topic that may be different to their current stream of science was motivation to participate and for those without a science background the motivation was to receive a '*science taster'* without having to commit to science. As with all previous experiments, any identifying data was coded to maintain anonymity.

10.3 Procedure

Twenty-eight postgraduate students were randomly recruited from across colleges in UCC through invitational email but 9 failed to respond when they were emailed their PowerPoint. On sign-up, students were randomly assigned to a study condition in Excel and then issued with the corresponding 'Science Taster' PowerPoint via email. Participants were free to engage with the PowerPoint in their own time. However, explicit instructions were included in the email and PowerPoint in relation to the parameters of the study. Nineteen postgraduate students from across the colleges at UCC voluntarily participated in T1 testing and out of those, eight participated in timepoint T2 testing.

A link to Quiz 1 was included in the last slide of the PowerPoint which gave access to the Google Form MCQ. An email with a link to access Quiz 2 was emailed to students 7 days after the date of their initial test and this system worked will with the students. Sample questions from both quizzes are as follows:

Quiz 1 recall question:

Q3. Which one of the following can inhibit complement binding and antibody mediated killing?

a) Polysaccharide O antigen
b) Flagellar H antigen
c) InvJ regulator protein
d) InvH gene
e) Vi Polysaccharide

Correct answer is (e)

Quiz 1 transfer question:

Q10. Predict the outcome if you were to remove the Salmonella pathogenicity islands (SPIs) from Salmonella.

a) Salmonella would be able to infect a host, but symptoms of disease would be less severe
b) Salmonella would become a non-disease causing strain
c) Salmonella would lose the ability to infect a host
d) Salmonella would die`
e) Salmonella would replicate uncontrollably

Correct answer is (b)

Quiz 2 recall question:

Q4. Select all answers that correctly describe the role Salmonella cytotoxin plays in causing disease:

a) Produces iron-chelating siderophores, using iron to aid in growth
b) Inhibits host cell protein synthesis
c) Inhibits complement binding and antibody-mediated killing
d) Produces at least ten different proteins that promote invasion
e) Allows Ca2+ to escape from host cells

Correct answers are (b) and (e)

Quiz 2 transfer question:

Q9. Given your learning of Salmonella virulence factors, which would be a better term for Salmonella infection?

a) Food poisoning – through toxins produced by bacteria
b) Direct contact – through infection from a contaminated surface
c) Indirect contact – through infection by passing around a contaminated object
d) Foodborne infection – through live bacteria
e) Aerosol infection – transmitting bacteria through sneezing, coughing and droplets.

Correct answer is (d)

10.4 Methodology of analysis of results

Non-parametric statistical testing was required as descriptive statistics revealed large standard deviations between some of the groups, in addition to demographic variation amongst participants. Although the *Kruskal-Wallis* test is the non-parametric alternative to a one-way ANOVA, it demands a minimum of 5 samples per group to be valid. As some of the groups had less than 5 samples, they were compared pairwise using the non-parametric *Mann-Whitney U* test.

10.5 Results

T1: Only two results were returned for the Mental Assembly group in T1 which was too small for comparison with the other groups. Hence, Mental Assembly results were excluded from further statistical analysis. For the same reason, the Guided Assembly group were excluded from analysis in T2. One student took Quiz 1 twice and was therefore excluded from analysis for both timepoints.

The null hypothesis for the independent samples (Unguided Assembly vs. Free Recall vs. Neutral vs. Guided Assembly) stated there was no difference between group means for learning (H_0:μ_1=μ_2 = μ_3 = μ_4). The alternative hypothesis stated that at least one pair of means would differ from each other for learning (H_A: $\mu_i \neq \mu_{j,\ for}$ at least one pair of groups where i, j = 1, 2, 3, 4 and i ≠ j).

A Mann-Whitney test indicated that learning was greater for those in the Unguided Assembly group (*n* = 4, *Mdn* = 32.5) than for those in the Neutral group (*n* = 4, *Mdn* = 22.5); *U* = 1, *z* = -2.071, *p* = .038, *r* = .73. The effect size 'r' is calculated using the following equation: r = z/square root of N, where N = total number of cases. Although the effect size appears to be large according to Cohen's (1998) criteria of a small effect size = .1; a medium effect size = .3 and a large effect size = .5, (Pallant, 2011) the overall statistical power of the test was very low due to small sample sizes and results must be interpreted in that context. A statistically significant difference was also found for learning between the Free Recall group (*n* 5, *Mdn* = 35.5) vs. Neutral group (*n* 3, *Mdn* = 22.5); *U* = 1, *z* = -2.252, *p* = .024, *r* = .8. Again, although a large effect size was reported, the overall statistical power of this study was very low and requires further testing.

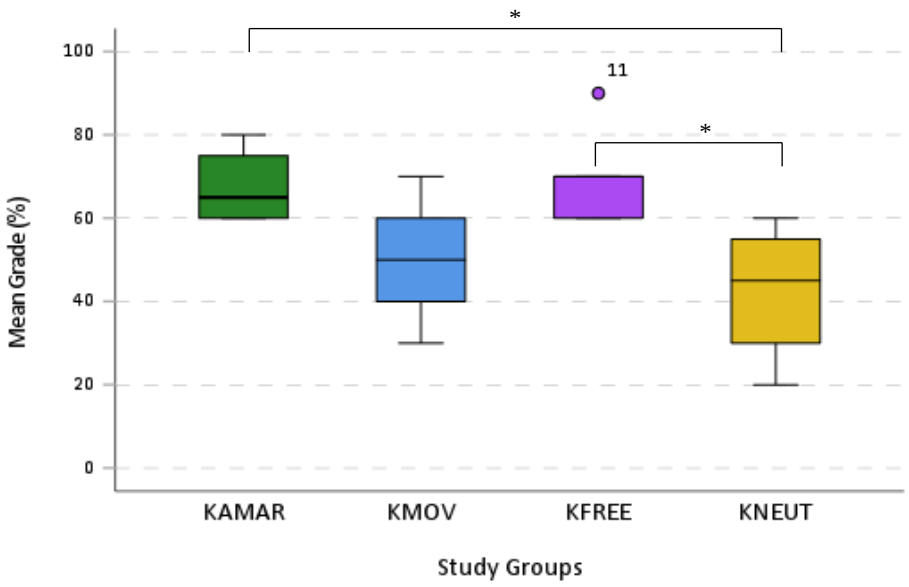
No statistical difference for learning was found between the Unguided Assembly and Free Recall groups (*U* = 9, *z* = -.261, *p* = .794, *r* = .10) or between the Unguided and Guided Assembly group (*n* 3, *Mdn* = 25.5); *U* = 2.5, *z* = -1.26, *p* =

.208. Despite a 10% higher grade for learning in the Free Recall group compared to the Guided Assembly group, no statistical significance was found (U = 3, z = -1.383, p = .167. Nor was there any statistical significance for learning between the groups Guided Assembly and Neutral (U = 4.5, z = -.535, p = .593. Thus, we failed to reject the null hypothesis (see Figure 10.1 a).

T2: The null hypothesis for the independent samples (Unguided Assembly vs. Free Recall vs. Neutral) stated there was no difference between group means for learning (H_0:μ_1=μ_2 = μ_3 = μ_4). The alternative hypothesis stated that at least one pair of means would differ from each other for learning (H_A: $\mu_i \neq \mu_{j,\ for}$ at least one pair of groups where i, j = 1, 2, 3, 4 and i ≠ j).

The best retention in long-term learning was returned for the Unguided Assembly group (n 4, *Mdn* = 49.8) and the lowest for the Neutral group (*n* 4, *Mdn* = 37.5). However, no statistical significance was found between the two groups for long-term learning retention (U = 7, z = -.290, p = .722). There was no statistical significance indicated between the groups Unguided Assembly vs. Free Recall group (*n* 4, *Mdn* = 40.5); U = 8, z < .0, p = 1.0. Nor was there any statistically significant difference found between the Free Recall and Neutral groups (U = 7.5, z = -.145, p = .885. Thus, we failed to reject the null hypothesis (see (see Figure 10.1 b).

A



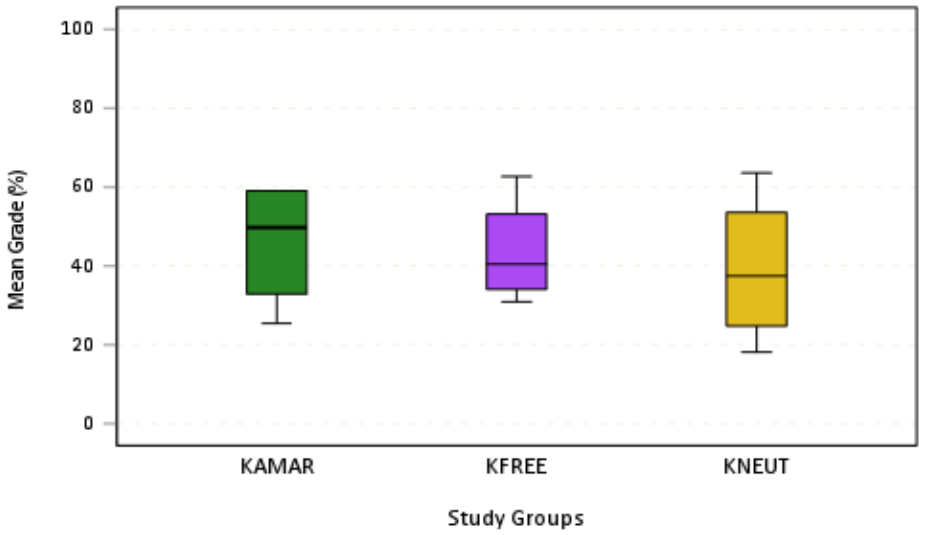


Figure 10.1 Experiment 8 Comparison of Postgraduate Study Results. Boxplot (A) results from T1: Unguided Assembly (M = 67%) vs. Guided Assembly (M = 50%) vs. Free Recall (M = 70%) vs. Neutral (n 4, M = 43%). Boxplot (B) results from T2: Unguided Assembly (M = 46%) vs. Free Recall (M = 44%) vs. Neutral (M = 39%).

10.6 Experiment 8 Discussion

Due to the poor response in general and the variable response of students who had initially volunteered to participate, the sample sizes for both timepoints in this experiment were very low. It is possible that on receipt of the PowerPoint, some students may have felt daunted by the complexity and advanced nature of the content, especially for those without any ties to science. Nonetheless, it is interesting to note that some of the students who returned the highest results across both timepoints had no prior or current involvement with science and actually surpassed some students who were studying science at postgraduate levels 9 and 10.

This is an interesting and unexpected outcome in terms of the potential for the KLS to act as a practical learning tool with highly advanced science. The lesson was entirely self-directed without the presence of a lecturer and conducted in a very short 15-minute timeframe for learning. There was no negative report from any participant. Bear in mind, the lesson was presented as it was printed in the textbook *Brock's Biology of Microorganisms* (Chapter 3, section 3.4.4) with relatively minimal content to support learning. Also, no background information was provided to scaffold understanding for the topic. This appears to fly in the face of all educational psychology going back to the earliest of theorists. As discussed in detail in Chapter 2, the prominent theories that emerged from initial animal studies and

which were adopted and adapted by psychologists and scientists (and sometimes, charlatans) as learning evolved and technology advanced, all have one thread in common and that is, that new knowledge is built and supported by prior knowledge.

It would be presumptuous to over-inflate the results of this small study, but it does appear that the KLS framework may have more potential than anticipated, for learning complex, abstract science topics even amongst those who are not scientifically inclined. Because of the ability of the KL lesson to support learning in this way, with more widespread empirical testing it may prove to be a powerful formative learning and assessment tool of the future.

CHAPTER 11

CONCLUSIONS AND RECOMMENDATIONS

11. Summary of Methodology and Results from all 8 Experiments

The research methodology of all eight experiments centred around the constructive alignment of teaching and learning activities to assessment; and to the design, recruitment and implementation of each experiment. Great care was taken in the research design to ensure that the method of data collection ensured reliability and validity. This included using a substantial lesson in the highly accessible PowerPoint platform, on three molecular science topics of relevance to second and third level education; recruiting students at different levels of academia; engaging the assistance of secondary school teachers to conduct the study remotely; developing rubrics for marking exams and the assembly of diagrams in an unbiased and transparent manner and developing a coding system to maintain the anonymity of participating students and schools.

To test the aim of this thesis for realistic use beyond research, it was important to choose sufficiently challenging science topics that are required learning for students at various levels of science education, from second level to postgrad status. Despite the low statistical power and limitations acknowledged for several experiments, a pattern for learning emerged across all experiments. An overview of the mean grades and statistical analysis of results are presented in Table 11. The experiments for which a kinaesthetic assembly came out as the condition with the highest grade in a single timepoint or in T1 (though not all statistically significant) were, experiments 1, 2, 3, 5 and 7. Experiments for which a non-kinaesthetic assembly condition returned the highest grade in T1 (though not all statistically significant) were experiments 4, 6 and 8. The experiments for which a kinaesthetic assembly came out as the condition with the highest grade in T2 (though not all statistically significant) were experiments 5, 6, 7 and 8. The single experiment in T2 for which a non-kinaesthetic assembly condition returned the highest grade was experiment 4.

Table 11 Summary overview of all KLS experiments' results

Groups	T1 (*n*)	T1 (*M*) %	T2 (*n*)	T2 (*M*) %
Pilot Studies				
KLS Test	*13*	91	-	-
Control	*13*	78	-	-
Exp 2				
KLS Test Interaction	*7*	57	-	-
Control Non-interaction	*8*	53	-	-
Exp 3				
KLSA	*4*	75	-	-
KLSM	*2*	88	-	-
KLSR	*1*	65	-	-
Control	*1*	35	-	-
Exp 4				
KAMAR	*28*	77	*21*	33 — *p* =.016
KMOV	*28*	80	*22*	25 — *p* <.001
KREC	*29*	87	*18*	43 — s.s.
Exp 5 Sub Study				
KAMAR	*14*	78	*13*	37
KSTAT	*14*	73	*12*	36
Exp 6				
KAMAR	*40*	74 s.s. — *p* = .031	*36*	54
KFREE	*38*	64	*37*	47
KNEUT	*38*	75 s.s. — *p* = .021	*35*	52
Exp 7				
KAMAR	*42*	52	*30*	30
KMOV	*7*	70	*7*	52
KFREE	*21*	46	*15*	43
KSTAT	*30*	53	*21*	40
KNEUT	*30*	50	*20*	34
Exp 8 Sub Study				
KAMAR	*4*	68 s.s. — *p* = .038	*4*	46
KMOV	*3*	50	*2*	31
KFREE	*5*	70 s.s. — *p* = .024	*4*	44
KNEUT	*4*	43	*4*	39

The Guided Assembly group tended to perform better than the Unguided Assembly group in immediate post-study testing for timepoint 1. However, three out of four of the studies in which the Guided Assembly condition was used had sample sizes that were far too small to generalise further. Experiment 4 was the first timepoint test with a strong sample size and in this instance Guided Assembly outperformed Unguided Assembly in T1 but Unguided Assembly proved more robust for T2. Unguided Assembly also tended to show more robust long-term knowledge retention in comparison to conditions which initially showed stronger T1

results, as seen in experiments 4 (Unguided Assembly & Guided Assembly), 6 (Unguided Assembly & Neutral) and 8 (Unguided Assembly & Free Recall).

The challenging Mental Assembly group proved particularly interesting and is a condition that would be worth re-testing in a larger study and amongst the users who would stand to benefit most from its application to science, e.g., those with a physically limiting impairment or learning disability which affects written communication.

There are calls for less non-experimental qualitative studies, in favour of more tightly controlled, randomised control trials (RCT) (Torgerson & Torgerson, 2001). Ideally, these RCTs should include the use of a placebo curriculum as a control to avoid the 'Hawthorne Effect,' the phenomenon of improvement across all conditions being evaluated when participants are aware they are part of an experiment as opposed to receiving curriculum under normal circumstances (Wellington, 2000; Shute et al., 2016).

Although RCTs can face ethical criticism for withholding a condition that may be beneficial to some participants, this study provided comparison groups that were modifications of some of the current best recall techniques for learning, e.g., Karpicke's 'retrieval-practice,' (2011; 2017; 2020) and Bui's free-form note taking on a computer (Trafton & Trickett, 2001; Bui et al., 2013; Chi & Wylie, 2014). As the effectiveness of the remaining techniques was unknown at the time of testing, it was not unethical for a participant to be added to any of the groups. Undergraduate students were well informed that participation would involve applying a specific study technique toward learning a mandatory topic of their course and therefore, it was not unethical if a student took the personal choice not to participate.

An overall pragmatic RCT approach was adopted and KLS lessons were delivered to students within the PowerPoint format they are most familiar with for lecture delivery. All participants were provided with the same lesson content represented identically, except for the inclusion of slides with learning aids specific to the condition being tested. In the case of secondary schools, students were provided with a topical lesson from the Leaving Certificate Biology syllabus on DNA transcription and translation although not all students were taking science, nor was there a requirement for them to be doing science to participate.

Feedback was very positive as relayed directly by teachers and there is scope to continue the KLS study amongst a broader selection of secondary schools

nationally. This is an especially promising outcome from this research as it attempts to address many of the concerns that persist both nationally and internationally, including a mechanism for confidential teacher grading, maintaining student anonymity, and a formative assessment tool in the affordable, accessible PowerPoint format which enables students to self-check their learning as they progress and hopefully, provide the necessary motivation to delve deeper into science concepts. Ideas that emerged to overcome research hurdles and which were applied successfully were:

- the use of study codes to support anonymity while maintaining traceability.
- qualitative codes to ensure groups were demographically balanced.
- a more nuanced marking scheme for grading multi-select questions quickly and reliably.
- interactive grading rubric in simple PDF format to enable quantification of concepts expressed as various biomolecular scenarios.

Student results were matched only to study codes, the codes being identifiable only to the various study conditions:

> *"One key feature of a good RCT is blinded assessment of outcome. Thus, although it is not a necessary requirement to mask the intervention from teachers and pupils by using a dummy, placebo or sham educational intervention as a control, it is important that the researcher who assesses the outcome of the trial is blind to the allocated intervention. If blinded outcome assessment is not undertaken observer bias might occur" (Torgerson & Torgerson, 2001, p. 324)*

As most students participated online and especially in the case of secondary school students and post-graduate students, it was possible to retain a blind outcome amongst the researchers, but as an additional precaution, a bias in marking was avoided by creating a strict rubric for grading quizzes in Google Forms. Again, through the assignment of study codes, results were downloaded anonymously from Google forms into Excel and then re-aligned with the original grouping of the study conditions. This meant no bias was possible in calculating results.

Recruitment was an ongoing issue throughout the three years of KLS development. A concerted effort was made to increase volunteer recruitment by setting up a SCIOPTLE Club which would provide exclusive access to a dedicated Instagram account and YouTube channel for students who signed up to KLS studies.

Students were informed of the club by email and lecture address, but interest was poor and was eventually dropped as a recruitment tactic.

The advantage in developing an online kinaesthetic assembly approach (alongside other KLS compatible approaches that were non-interactive) for use in the affordable, accessible platform of PowerPoint, is that it provides a route for other educators to create modifiable content for simulating science scenarios without resorting to more expensive and generic, ready-made simulations which are generally unmodifiable directly by the user. Thus, the educator can continue to build upon the creativity of their own KLS PowerPoints or of others, as well as adapt the level of content to suit different ages and knowledge levels through the addition or omission of pictorial content. For the learner using the PowerPoints, their design, layout and delivery capability facilitates asynchronous progression of learning that can be self-paced and self-directed, but which completely compliments and aligns with synchronous in-class learning.

A limitation of this KLS study is that it was not possible to directly assess cognitive processing during learning, e.g., through the use of EEG, as a trade-off for ensuring practical significance in testing KL lessons realistically. However, student feedback formed an important role in lesson design and for the ongoing improvement of its delivery and implementation. Students reported on the elements they found difficult and on what they found most enjoyable and/or helpful to their learning and group results tended to reflect student feedback.

In terms of practical significance, the key goals of the KLS framework were met and it proved readily sharable, scalable and expandable for learning biomolecular science at multiple levels, from second level to postgraduate. Regardless of the statistical significance revealed in some of the experiments, the KL PowerPoints can be justified as having practical use beyond this research as they enable rapid evaluation by the teacher of student engagement and as a means to increase/decrease the level of difficulty for content. In addition, lessons can employ a variety of KL task formats for use as a UDL compliant revision tool. That one teacher verbally requested permission to continue using the DNA Research Lesson PowerPoints, pictures and video in his biology classes is testament to the practicality and ease of use of the KL PowerPoints. As such, the KLS framework of lessons and in particular, the online kinaesthetic assembly approach provides a simple, elegant

model with huge potential limited only be one's creativity, for application toward learning the complex and invisible aspects of advanced biomolecular science.

CHAPTER 12

CONCLUSIONS AND RECOMMENDATIONS

12. Introduction

This chapter summarises the research findings arising out of the main research question, as well as discussing how these findings relate to the aims and objectives of this research. In addition, the contributions of this research to knowledge and understanding in this field of study are discussed as well as the limitations of this research project. Recommendations for future research opportunities are outlined throughout and summarised at the end. The overall research project will be referred to at times as the KLS study.

This research hypothesised that online kinaesthetic approaches to teaching and learning would be highly effective towards helping students grasp new science concepts, as well as helping them understand advanced biomolecular processes and for enhancing long-term knowledge retention. A mixed-methods study was conducted to test the validity of the hypothesis and involved the following:

- Three pilot studies were designed to develop and assess the implementation of simple KL approaches based on a kinaesthetic assembly model in the affordable, widely accessible platform of PowerPoint. These approaches were successfully integrated into each lesson to ensure engagement in self-directed online learning.

- Three randomised trials were conducted to test, evaluate and optimise KL approaches for science learning. Two of these trials involved science and medicine undergraduates and one trial expanded the study for third party use by secondary school teachers in order to test the scalability of approaches to lower knowledge levels.

- Two sub-studies were carried out. One explored a static disassembled version (Mental Assembly) of two interactive assembly approaches (Unguided Assembly and Guided Assembly), and the other tested the application of KL amongst post-graduates using a challenging science lesson, regardless of science background and without providing background science information for the topic.

Through this iterative process, it was possible to develop the KLS framework to guide the creation of online science lessons incorporating kinaesthetic assembly-based learning approaches, i.e., the KL lesson format. This framework has proven

adaptable toward learning molecular science at different levels of academia, as exemplified by three different science topics: the lac operon gene regulation system, DNA transcription and translation, and *Salmonella* virulence factors.

12.1 Main Research Findings

The main research question arising from the research hypothesis was whether it was possible to develop online approaches for improved KL in science and evaluate them for realistic use amongst students at the higher levels of academia. Hence, the main aim of the thesis was to examine (a) current online KL, (b) the context of its use and (c) based on what is understood as kinaesthetic, develop an online KL approach suitable for application to an advanced molecular science topic(s). The main objectives focused on the (a) identification, design and development of novel online KL approaches and (b) the evaluation of the efficacy of these approaches in learners.

12.1.1 Examination of current online KL

Chapter 1 provided an overview of the general learning and digital landscape, including controversy surrounding the use of online digital media and its potential effects on the brain (Greenfield, 2003; Carr, 2011; Sparrow et al., 2011; Firth et al., 2019). The biological processes of learning were introduced, leading to a discussion of what constitutes KL traditionally and how that might be translated to online KL. A major hurdle in beginning to address the main research question, was the paucity of research in the literature for online KL and especially so in relation to the molecular sciences. This was highlighted in Table 1. Disparities in how different disciplines referred to 'kinaesthetic' led to an in-depth literature review in Chapter 2, to better understand KL and the context of its use.

Neuroscience provides the most detailed understanding of learning at the neurobiological level, but the language of neuroscience is often inaccessible to many. It is also recognised generally that neuroscience is not included in education research to the extent that it should (Mayer R, 2018). Hence, education psychology is the dominant field for researching and publishing education related studies. A great advantage of this thesis was the interdisciplinary approach toward researching

and implementing the KLS. This researcher comes from a neuroscience background (including the study of biochemistry) and has teaching and learning experience in both the science and education domains. Thus, it was possible to critically appraise both the neuroscience and education psychology literature extensively in Chapter 2. A contribution to research arising from this interdisciplinary approach, is a more cohesive understanding from both disciplines of what 'kinaesthetic' means in terms of learning.

12.1.2 Translating KL to an online learning approach for science

Once the concept of KL was deliberated and clarified in more detail, the context in which KL might be translated to an online platform was investigated in terms of its application to molecular science. In doing so, fallacious learning models were reviewed and the more robust theories around what underpins memory for learning and understanding was discussed in detail. The use of digital technology in gamification, lab simulation and virtual reality (VR) although acknowledged here for their kinaesthetic qualities, remain largely tools employed in learning rather than tools to promote and enhance learning. Results from wider research are also mixed as to whether media exerts more influence on learning, motivation and achievement than the methods employed to learn (Mayer, 2003; Makransky & Peterson, 2021; Liu, Meng & Roy-Campbell, 202l). Studies comparing high immersion VR to low immersion computer-based lessons, indicate a media effect in favour of low immersion lessons (Mayer, 2003; Mayer et al., 2005; Makransky et al., 2019) as discussed in Chapter 2, section 2.1.1. PowerPoint was chosen as the affordable, accessible (key parameters) online platform in which to build a KL approach and is an example of a low immersion medium.

In contrast to the media effect however and in agreement with Clark (1994), this study concludes that there is a strong methods effect on learning as all KL lessons were presented identically across conditions via the same media. Contradictions regarding a media or methods effect should not be surprising. The brain is not locked into one particular mode of learning, as can be seen from the neuroscience discussed in Chapter 2. Clearly, both media and methods can influence learning depending on a variety of factors. Perhaps the difference in any outcome between a media or methods effect may be due to cognitive overload when extraneous details are added to the lesson itself (Clark & Mayer, 2008; De Jong,

2011). Apart from these early technical difficulties encountered during early testing of the KLS (experiments 1 and 2), the variation in overall results for this KLS study arose when different learning methods in the form of study tasks were employed. However, even when media was not ideal (video format of experiment 2 and deliberately challenging layout of experiment 8) which could have caused cognitive burden, the methods used still yielded different results between study groups. The neuroscience strongly supports a methods effect as observed in this study and in agreement with Clark (1994), from findings that movement, practice and experience are intrinsically linked to our cognitive development (LeDoux, 2002; Hazeltine & Ivry, 2002; Greenfield, 2003; Kandel et al., 2014; Leisman et al., 2016; Camina & Güell, 2017; Bédécarrats et al., 2018; Heyes & Catmur, 2022).

It was observed in the pilot studies and in the secondary school study (with one teacher), that instructions were frequently passed over. This is similar to Carr's (2011) observation of 'skimming' over information without paying due attention to the content and is also a feature of cognitive overload. Through conversation with participants and written feedback, it was established that failure to follow instructions for downloading the PowerPoint, playing the video(s) and engaging in tasks was the primary root cause of 'technical difficulties' encountered. Once instructions for downloading PowerPoints were made more stepwise and more visual, almost all perceived technical difficulties were resolved.

Challenges to learning science were discussed down to the level of science vocabulary (Carrillo-de-la-Pena et al., 2009) as well as difficulties in visualising processes that are not easily related to our common everyday experiences. A concrete example of this was shared in Figures 2.2 and 2.3, comparing the science language and graphics between the scientific domains of anatomy and the molecular sciences. In recognising these challenges, special attention was paid to the written language of the lesson, giving rise to a *Concept Table* (Table 3.3). Although the potential could be seen for the concept table to be used as a tool for scaling the level of science up or down for different knowledge tiers, in practice, it was far too time consuming to continue using or to recommend to other researchers.

The science illustrations for the KL lessons also underwent an iterative process of repeated drafting on paper and in digital format before agreement was reached on the final visual representation of content, in the form of independently movable science 'icons'. This required a high degree of creativity and technical skill

in digital illustration. However, there are many free online websites which offer pre-drawn shapes and images for science, e.g., Biorender and Lucid illustration libraries. PowerPoint itself also enables a good degree of illustration via drawing tools, images and icons for insertion into slides. Once the illustrations were finalised, it was a quick process to assemble multiple diagrams. Icons were interchangeable for use in different topics (Lac Operon and DNA) and at different knowledge levels, making them an agile and sustainable resource.

The practical aspects of digital illustration incurred a cost, requiring a relatively inexpensive student subscription to Adobe illustrator and the once-off purchase of a Wacom Cintiq 16 drawing tablet which was more expensive. In comparison to lab bench fees, the costs incurred for this research were quite low and should not be prohibitive to future research in this area. Given the affordability and versatility of digital illustration, this research recommends exploring science illustration (pictorial) in relation to creating visual models to enhance students' mental image processing, encourage creativity and to disseminate science to a broader audience. Feedback was positive for the highly illustrated presentation of the lessons from teachers and students alike and the general expression was a hope to see more content presented similarly.

Although the KLS framework sets out a means of representing science content more visually, there are mixed results from research as to the effectiveness of drawing activities for learning (Wu & Rau, 2019), despite the high level of creativity involved. The KLS enables students to interact and build an overall picture of various biomolecular scenarios, thus creating a strong visual model without requiring any art skills. Studies have demonstrated that drawing is effective for learning if used to construct new knowledge from prior knowledge and that students who trace over images or copy them, learn less (Mason et al., 2013; Gagnier et al., 2015). The KLS study deviated from this by giving students advanced learning material for which they had little to no prior knowledge. The rationale behind this was to provide a robust challenge to the various KLS approaches for stronger empirical evidence of their effectiveness, as opposed to the lighter lessons typically given in much of science and psychology-based research, as discussed in chapter 3, section 3.3.2. Another reason was to explore if the KL lesson format would be favourable for learning amongst those who may have less of an aptitude for science. Because the subject pool for most of the experiments involved students who were studying

science or medicine and already had a proven aptitude for science, it was necessary to give them a more advanced topic to ensure any learning gains could be attributed to the methods employed, not to their scientific knowledge.

Interestingly, results from experiments 3 (an undergraduate pilot), 7 (secondary schools) and 8 (the post-graduate sub-study) which recruited students from disciplines other than science, returned relatively comparable quiz results (i.e., a passing grade > 40%), to experiments with science and medicine students. This achieved one of the sub-aims of the study: to create a framework that would be scalable and expandable to other disciplines and which could provide continuity in learning when progressing through different knowledge levels. This warrants a recommendation to further explore the scalability and expandability of the KLS framework.

In agreement with some of the research findings discussed by Wu & Rau (2019), the Unguided Assembly unguided assembly group generally took longer to complete study tasks (as confirmed by Google Form timestamps) than the Guided Assembly guided assembly group (instance-based training) but the latter group tended to have less robust long-term learning than the Unguided Assembly in timepoint 2 testing. This upholds broader research findings that greater mental effort, whether drawing or completing a task, leads to better long-term learning (Seel, 2017).

The development of lesson videos to complement the written lesson content emerged from student feedback recommending videos as a good resource for learning. An innovative twist in creating the videos was to use the same icons from the lesson slides to create the animated videos. The text of the lesson was used exactly as the transcript for the video narration. There is little in research to guide video creation from an instructional point of view (Fiorella et al., 2017) and especially for science. Hence, this format of the KL lesson and video is an important contribution to research (Figure 3.3). In the context of the KL lesson, the video was positioned as a pre-lecture to prime learning and in the case of the Unguided Assembly and Guided Assembly study conditions, to informally set the expectations for 'to-be-performed' actions (Fiorella et al., 2017) for assembly. Cognitive overload can be a risk when using constructive models such as the Unguided Assembly and Guided Assembly approaches (Chi & Wylie, 2014). Prior training in how to use models can greatly mitigate this risk (Seel, 2017) and this was achieved

by providing a simple practice PowerPoint in advance of the first timepoint session, in addition to the lesson video and detailed instructions.

Analysis of data from the pilot studies was favourable for the video lesson when technical issues were removed. Several secondary school teachers also expressed satisfaction with the video and general lesson layout. However, removal of the video from later experiments did not appear to have any impact, positive or negative, on learning, except perhaps for the small postgraduate sub-study which used the intensely complex *Salmonella* Science Taster lesson. It may be that the provision of a video for that particular lesson could have improved learning for some. Another explanation lies in the construction of the lesson as great effort was put into ensuring the clarity of text and illustrated content to ensure they did not present as confounding media for learning. In addition, more illustrations appeared in the KL lessons than would typically appear in a standard textbook and the lesson presentation overall was modelled on recommendations from Mayer's *principles of multimedia* (Clark & Mayer R, 2008). Mayer has also shown that static media (images and text) can be as effective as animations for learning (Mayer et al., 2005) albeit other research does not support his finding, as per reviews by Tversky and colleagues (2002) and Seel (2017). However, this could well explain why removal of the Lac Operon lesson video did not appear to impact learning results to any discernible degree. Without further research, it is not possible to give a definitive answer. Hence, a further recommendation arising from this study is to investigate the role of pre-lecture videos in improving science learning, especially within the bespoke format of the KLS framework. This would be a highly relevant avenue of research given the general progression of education to more blended and online learning formats.

12.1.3 Critical appraisal of the literature

To prepare an effective online KL approach for use in academia, it was necessary to review the literature further, to assess the current state of science practice in education. Key findings from this review in Chapter 3 highlighted problems associated with over-reliance on the high-stakes assessment model, the need for more continuity in learning approaches from second to third level and the potential for formative assessments to improve learning more holistically, through

self-paced and self-directed practice; these would also require a means of self-evaluation to assess progression.

Other learning factors discussed extensively in chapter 3 included student-teacher relationships, in-class dynamics, lesson pacing, teaching to a test and the shared perception between students and teachers that science is difficult to teach and learn. Many studies recommend taking advantage of digital technology to reconceptualise assessments so they can measure learning more fully. This includes the creation of TREs encompassing more engaging text, diagrams and animations to provide more experiential learning (Shute et al., 2016). As a contribution to research, the KLS framework attempts to address these issues through the provision of KL lessons that facilitate self-paced and self-directed online science learning. Self-evaluation is also possible, while the educator can rapidly assess progress formatively through visual inspection of completed tasks. This was evident in experiments 2 and 3 from KL lesson PowerPoints which were returned to the researchers. Teachers in secondary schools did not need to teach or grade the KL lessons, making the KL lessons a more objective formative assessment and learning tool. Further testing to fine-tune the KL assembly model using greater sample sizes and amongst other disciplines is recommended, to reveal more potential applications of the model.

12.2 The Development of Novel Online KL Approaches

The literature was summarised and synthesised to define kinaesthetic learning more clearly as an experiential approach that facilitates repeat practice with something tangible. This helped to inform the translation of the offline kinaesthetic approach of assembling a model (to better understand the functional parts and roles of something) into an online version of the same. The online KL assembly version for science involved assembling the icons of biomolecules into a whole diagram to better understand their functional roles and significance within a biochemical process. This was completed in five principal ways by:

i. Merging best practice guidelines from e-learning with empirically sound learning theories, to formulate a list of criteria to structure the KLS framework (Table 2.3).

ii. Testing the KLS for practical application (chapter 3, section 3.3.1) and realistic use with molecular science topics (chapter 3, section 3.3.2) by achieving the following:

    a. Adapting a 1-hour advanced molecular science lecture on the Lac Operon and breaking it down into its component parts to create a KL lesson optimised for self-directed learning in under 30 minutes (experiments 1-6)

    b. Scaling the KL lessons for lower knowledge tiers using the DNA Research Lesson and expanding it to secondary schools for third-party, remote implementation (experiment 7).

    c. Creating a challenging postgraduate KL lesson on *Salmonella* virulence factors based on an excerpt taken from a third level textbook recommended to microbiology students in UCC (Brock's Biology of Microorganisms) (experiment 8).

iii. Developing learning outcomes for the study and constructively aligning them with the teaching and assessment methods to be used.

iv. Assessing the KLS (as per Chapter 3, section 3.7.1) using recognised exam formats in academia (MCQ, SAQ, MSQ) with questions of a comparable level to the science lesson. Transfer questions tested deep understanding and the ability to hypothesise and apply learning to novel situations (Clark & Mayer, 2008; Makransky et al., 2021).

v. Providing a means of self-directed learning by embedding task slides after 'expert' lesson slides (Wu & Rau, 2019) and allowing students to self-evaluate their learning in experiments once tasks were complete.

Initial ideas for several KL approaches were conceived and analysed for suitability against the evaluation criteria for developing the KLS framework (Chapter 3, section 3.3.1) and Table 3.1. Ultimately, a version of the original KLS1 Assembly and Controlled Disassembly model was progressed and developed to the assembly models of Unguided Assembly, Guided Assembly and Mental Assembly.

Albert Bandura proposed that learning is supported when learners can self-evaluate and analyse their progression (McLeod, 2016), while Gardner (2013) maintained that true understanding could be demonstrated by a learner who could disseminate knowledge in diverse ways and in novel situations, including through the use of technology. Similar to Gardner, others have promoted moving toward more experiential learning approaches that can encourage the learner to think more critically and independently (Gegner et al., 2009; Bree, 2018; Co, 2019). The KL

lesson tasks overall, facilitate the self-efficacy for learning of students who can return to previous slides to self-evaluate their progress as Bandura suggested and takes full advantage of technology as Gardner recommended, to enhance the lesson layout, tasks and accessibility for kinaesthetic learning in PowerPoint. Thus, the student can challenge illusions of learning and practice repeatedly to cement learning for new concepts (Wellington, 2000; Smith, 2002; McLeod, 2019). It is also possible for the student to assemble icons from Unguided Assembly, Guided Assembly and Mental Assembly, into multiple hypothetical scenarios beyond those presented in the lesson, providing a very useful tool for constructive learning (Chi & Wylie, 2014; Bree, 2018) and creative, self-paced exploration (Gardner, 2013; Shute et al., 2016). Furthermore, this research recommends embedding various hypothetical scenarios into traditional summative exam formats for testing transfer knowledge (i.e., deeper understanding). This may lead to a wider range of creative teaching and learning activities, and assessment options.

12.3 Empirical Evaluation of the Efficacy of KL Approaches

One of the strengths of an outstanding scientist is the ability to think creatively and flex the mind to new areas of research that may at first appear too simplistic to be of value (think of what Isaac Newton's bump on the head lead to), or too impossible to achieve. But as Einstein famously put it:

> *"Imagination is more important than knowledge. For knowledge is limited to all we know and understand, while imagination embraces the entire world and all there ever will be to know and understand. Imagination encircles the world." - Albert Einstein (1879 – 1955)*

The question then is why does research appear to be lacking in creativity (Runco & Abdullah, 2014; Van Aken, 2016)? It may be that many researchers have become overly focused on becoming published and will not waste time exploring avenues that may not produce statistical significance. In reviewing the publication history of three top psychology journals, namely, the '*Journal of Experimental Psychology: General* (JEPG), *Journal of Personality and Social Psychology* (JPJP) *and Psychological Science* (PS), Masciampo and Lalande (2012) found that:

> *"Researchers were especially unlikely to share their published data for reanalysis if their p-values were just below .05."*

They discuss the speculation that researchers may be monitoring data continuously until they observe the desired results for reporting, or that results are manipulated through the selective omission of outliers or covariates (an example of a covariate for the KLS experiments would be a demographic detail gathered on participants that make up a sample, such as an identified learning disability, English as a second language etc.). This, in spite of the fact that the significance threshold of (.05) is an arbitrary figure (Rohmann, 2018) that is only meant to help researchers interpret results within the broader context of the study and not to dismiss a result outright as entirely useless if it should happen to carry an extra (.02) of a difference:

> *"Because of this confusion, as well as rampant misuse, **'p' has become controversial and has even been banned from some scientific journals entirely** [1]… Their use detracts from potentially interesting results that do not meet the significance threshold due to factors such as few outcome events. Failing to publish results because they are "not statistically significant" (which is **not** the same as finding "no association") leads to damaging publication bias." (Rohmann, 2018)*

Hence, an important strength of this KLS study were the steps taken to produce KL lessons that would have true practical application in science education and research. KL lessons were tested empirically using qualitative and quantitative methods.

12.3.1 The Qualitative Data

At one point in the research, a discussion was held about whether this study should become fully qualitative (see Appendix F), as a wealth of information could be explored from different angles through written and verbal student feedback. Covid-19 restrictions were also newly implemented, leading to high levels of uncertainty regarding future recruitment and participation of students for quantitative studies. In choosing whether a fully qualitative approach is suitable, the advice is to consider the ethics relating to how much time and effort is required of participants (McGrath, Palmgren & Liljedahl, 2019). As the time required to complete the study session and quiz took an hour of the student's time and an extra ~30 minutes if participating in the second timepoint quiz, it was more appropriate for students to provide their insights on the KL study experience in a brief but pointed manner through email. This semi-structured approach guided students in the areas of interest

to the researchers, such as problems encountered or suggested improvements, without being too structured.

A moderate amount of qualitative data was gathered in the Participant Questionnaires with a view initially to compare results from experiments with student perceptions of how they would usually learn. Questions included typical study methods, perceived levels of distraction, handedness, learning disability, etc. On reading through the feedback, it became obvious early on that the typical methods reported aligned with what is already well established in research, i.e., note-taking is a preferred means of capturing lectures. As note-taking is also identified as being a successful approach to learning (depending on the type of notes taken) this angle of research was not new but comparing it to an assembly approach was new. Because of the novelty of assembly online, it would not be likely that a student would rank it highly as a 'learning preference' and indeed, this was found to be the case when students were asked. Students, educators or researchers might also have been reluctant to trust a KL assembly approach as a formative (and potentially summative) tool for learning and assessment without quantitative data to back it up.

VARK questionnaires were originally designed by Fleming (1992) as a formative evaluation tool to help students become more aware of their own learning preferences. VARK was adopted by researchers and educators alike, as a justification for tailoring lessons specifically to suit the learner's preference, despite Fleming's own protests that VARK is not meant to be used in that way as discussed in Chapter 2. VARKs limitation is that it relies on subjective feedback only and generally, is not paired with quantitative data to confirm any effects on learning. Where VARK and VAK have been tested empirically, results have not shown a learning effect (Sharp et al., 2008; Papadatou-Pastou et al., 2018; Newton et al., 2021). It was not desirable for the KLS framework or any KL lesson to be adopted by researchers or educators without trustworthy knowledge of their efficacy. It was concluded that objective quantitative data, along with pointed qualitative feedback was the best way to provide rigorous empirical measures on the KLS.

The data from Participant Questionnaires was used to create a concise set of codes in Excel for demographic details as outlined in Chapter 4, experiment 4. The use of codes is commonly used in qualitative research to manage large volumes of data (Braun & Clarke, 2006) and it became a very useful tool to ensure an approximately normal distribution across study groups for factors which might

otherwise have skewed data, e.g., English fluency, learning disability, prior science etc. This was achieved by applying the codes for demographic details to participants and was especially useful when sample sizes were less than ideal. Random assignment to groups was still possible as codes were applied prior to group assignment as outlined in detail in experiment 4. The demographic codes were complemented by the use of each student's unique study code. Thus, anonymity was maintained throughout the conduction of the experiments and in reporting all results, as assured to participants when relaying the ethics of this research.

A simple thematic analysis using NVIVO was applied retrospectively to student feedback to capture any themes or patterns that might otherwise have been lost on initial reading of the feedback. It was a suitable analytical method as it can be applied to small amounts of data (e.g., a paragraph) as well as to larger volumes of information. Fortunately, the feedback from students showed a very consistent pattern in relation to improving the layout for study tasks to motivate interaction with icons, providing animations, improving instructions and delivery methods. Feedback was very positive overall for the written language and illustration of lesson content, the video and the approach of including study tasks within the lesson itself. Negative feedback resulted largely from technical issues which reduced interaction or understanding of the lesson protocol. All feedback was incorporated into ongoing lesson improvement. Several students expressed appreciation for the move this research was taking in trying to improve and simplify science learning.

Overall feedback from secondary school teachers was resoundingly positive, including one teacher with no science background who stated he would be willing to teach the lesson on DNA transcription and translation using the KL lesson (teachers and students were not required to be studying science in experiment 7). In addition, one of the schools that participated asked if they could retain the PowerPoints to help teach that topic in future years. Others acknowledged the need for more innovative assessment and learning tools and encouraged the direction this research was taking to contribute to this area. This highlights the practical significance of the KLS framework and the feasibility for the KL lesson model to be applied to more science topics for further empirical research. Hence, this research recommends expanding testing of the KLS to more secondary schools and third level institutes nationally and internationally, as this was greatly impeded by the restrictions of the Covid-19 pandemic.

Results from all experiments were considered for their practical use beyond simply establishing statistical significance. A particularly exciting example of this is the Mental Assembly condition which is a very untraditional format for presenting and assessing science knowledge. It may seem like a simple concept to jumble up labels or elements of a diagram and ask the student to identify the correct from the incorrect, yet the grade achieved in the experiments which employed Mental Assembly (5 and 7) show predictive validity for the condition and learning that was closely similar to the ICAP's highest method for learning, i.e., interactive, as employed by the Unguided Assembly group through online assembly. Although Mental Assembly failed to reach the threshold for statistical significance, Mental Assembly has potential to support students who cannot easily perform fine motor movements. As the Mental Assembly approach may have potential in some student cohorts, more testing of this approach is merited.

12.3.2 The Quantitative Data

As can be seen from the KLS experiments, all results were reported transparently, with any deviation to the initial study parameters outlined in detail such as, the removal of outliers to comply with an adjusted timestamp for experiment 4 (Chapter 6, section 6.8, pg. 147) and the removal of the single anomalous outlier in the Unguided Assembly group for the correlation analysis in the same experiment (Figures 6.3, a & b). Limitations to the statistical analysis of experiments were outlined in the discussion following experiments and are further reviewed in Chapter 12. Appropriate statistical tests were applied in SPSS for parametric (ANOVAs and post hoc Tukey HSD) and non-parametric data (Mann-Whitney U test). A detailed grading rubric was created to guide the marking of the second quiz in SAQ format for experiment 4, which was the first two-timepoint quiz. This proved to be very reliable, with minimal variation between the two assessors who marked the quiz independently of each other. Grading was improved upon by devising a more nuanced marking scheme to assign partial marks to the MSQ quizzes used for the second quiz in subsequent experiments. This scheme better captured the long-term knowledge retained as opposed to assigning an all or nothing mark for answers as commonly used in academia (URL 9).

The assembly tasks developed for the KLS presented a new challenge for quantitative measurement. Instead of simply assigning points for labelled items in a

diagram, the goal was to measure recognition of and understanding for molecular components, their functional roles, structure and temporal order of a process depicted. The novelty of the study meant there was nothing to guide such measurement of assembly tasks. An interactive PDF rubric to guide the marking of each assembly task per slide was created in Adobe Acrobat Pro (link provided in Chapter 6, section 6.5). This enabled the correct assembly of tasks to be quantified reliably and compared with grade results from both the first and second quizzes in experiment 4. A strong correlation was found to exist between assembly and grade outcome. To this researcher's knowledge, nothing equivalent exists in research to enable this method of analysis and so, presents another important contribution to research. The rubric is quick and easy to use and readily adaptable to grade other assembly topics.

Pilot studies are not reported on statistically as their purpose is to evaluate whether a larger study is feasible or not and this study was in keeping with that principle. For the pilot studies, the qualitative data was most important although the group mean results and boxplots were included for a basic comparability between the various study conditions.

12.4 Validity in Testing

One of the aims of this thesis was to test any approaches developed as realistically as possible to provide construct validity, content validity, face validity and criterion validity (Chapter 3, section 3.3.1). This is a major limitation in many science and education research studies. As discussed previously (Chapter 3, section 3.3.2), the reality is that students would not have their learning judged on the ability to recall a word list (Karpicke & Blunt, 2011) or a short text-piece unrelated to their field of study (Mayer et al., 2005; Bobek & Tversky, 2016). In reality, undergraduate students will typically attend one-hour lectures and secondary school students, classes of approximately 40 mins. Therefore, topics that would actually be delivered to students at a later point in their course were chosen. These were adapted for learning in less than 30 mins through optimisation of the lesson layout and task content in PowerPoint, guided by Bloom's Taxonomy and the top e-learning principles of instructional design outlined in Chapter 2, section 2.1.6. In reality, students would most likely use their own digital devices to study from their location

of choice. For this reason, the KLS study utilised online remote delivery and self-directed completion of the KL lesson on student's own devices and from a location of their choosing. The video lesson served to mimic lecture attendance but removal of the video lesson in later studies (except Experiment 7) does not appear to have impacted achievement of the learning outcome.

12.5 Limitations of the Research Study

It was clear from the original design of this study that certain limitations existed. For example, there were limitations in comparing the standard of the online kinaesthetic framework to current literature or to guide its development, due to its novelty and the general lack of interdisciplinary research relating to KL. This necessitated the generation of criteria to help the researchers evaluate the evolving parameters of the KLS, based on current best e-learning guidelines. The KLS criteria list serves as a valuable reference for other researchers in creating their own KL lessons and is a meaningful contribution to the field of science education.

Much of the thesis focused on the design and development of suitable science content which needed a high degree of technical and art skills. Significant time was spent self-training in the use of Adobe illustrator, through Adobe online tutorials. Substantial time was also required to create the bespoke videos, i.e., the lac operon and DNA lessons, lac operon instructions (experiment 2) and teacher's instructions. Considerable self-training was also required for PowerPoint animation, Camtasia video editor and Audacity audio software, by using free online tutorials for all. The same time, equipment or software may not be available to others who wish to train in order to develop art skills or to create bespoke science illustrations and animations.

The challenge of Covid-19 restrictions seemed fortuitous in one sense for testing the KL lessons as realistically as possible. However, the impact was negative for some of the experiments and posed a serious challenge for student and secondary school recruitment. This was reflective of a trend in education that emerged post-Covid (Gamage & Perera, 2021; Van Beusekom, 2022). Relatively large student numbers were recruited for the main two-timepoint studies amongst undergraduates (experiments 4 and 6). The central limit theorem of statistics states that a sample size of 30 or greater will lead to a distribution of means that are approximately normal. The larger the sample size, the more closely that sample will reflect the

wider population it represents. However, when population parameters (e.g., demographics) are unknown, it is better to have a larger sample size for more trust in results. It was an unfortunate limitation that several of the experiments (experiments 3, 5 and 8) did not manage to recruit larger student numbers. This was despite the significant efforts made to market the experiments through the SCIOPTLE Club and to motivate student participation by offering additional learning supports. It was found by this researcher that the most effective way to recruit participants was to have a lecturer address a class and remind them repeatedly of the advantages of participating.

Closely related to the previous limitation, was the lack of power in setting up experiments (the pilot studies did not report statistics). Ideally, an a priori power analysis is conducted prior to any experiment to identify the ideal number of participants required to avoid errors in reporting the null hypothesis (Faul et al., 2007). For example, if a study has too few participants, the risk is higher for reporting a Type 2 error which means, not finding a statistically significant result when there is one (a Type 1 error is reporting a statistically significant result when there is none) (Pallant, 2011; Birkett, 2019). A power analysis was initially performed for experiment 4 but the numbers fell short of the ideal by a difference of 18. However, post hoc tests are frequently used in research where the parameters of a power analysis are not met, or where a power analysis has not been conducted in the first place. Once the ideal number of participants was established, subsequent experiments endeavoured to achieve this standard. Where it was not achieved, this limitation was acknowledged and results reported with caution.

There are some constraints to the random recruitment of students in this study overall. Firstly, in order to achieve realistic testing of science material at second and third level, it was necessary to limit the subject pool to students attending a secondary school or university rather than extending the invite to the general public. Furthermore, it was necessary to begin with students who would likely benefit from the use of a KL approach (and in keeping with Cohen's beneficence principle) as it had been envisaged originally to use the same students in a series of KLS experiments to test a variety of lessons over time. Testing over the timeframe of an undergraduate degree could be a recommendation but it would require significant investment of time, resources and personnel to accomplish. Hence, some of the experiments were necessarily limited to a science and medicine undergraduate

student cohort as the Lac Operon is a topic for study later on in their course. While this achieved a key objective of testing realistically, the power of a pure randomised study was somewhat reduced. Conversely, the codes also verified that students were not excluded for any demographic detail identified, i.e., gender, learning disability, language, etc., which brings a level of equality and conscientiousness to the KLS study that might otherwise have been lost.

Some experiments (3 pilot study and 8 post-graduate study) did invite students from across the university as opposed to specific subject pools, depending on the context of the experiment. It is interesting to note that some students who were not studying a science related discipline outperformed students who were (experiment 8) when using a self-directed assembly approach but sample sizes were very small. Statistics are used to make inferences and if the parameters of a particular statistical approach are not met, then statistical inferences cannot be made about any results arising from the study. Hence, it is not possible to generalise the results of the smaller experiments (i.e., 5 and 8) and this was an acknowledged limitation when reporting results. It would, however, be an interesting avenue for researchers to explore further as good grades were achievable amongst non-science students in comparison to postgrad level science students, albeit in a very specific context and for a single, short topical piece.

In recent years, researchers have become more aware of the effects of gender on learning and one of the objectives outlined in our ethical statement was to strive for greater gender balance. Coding enabled groups to be approximately normalised for demographic details in a nuanced manner that pure randomisation would not have allowed for. A randomised approach to recruiting students within their subject pool and sorting in groups in Excel was followed as much as possible within the parameters of the study. However, the time constraints of the KLS study did not allow for scrutiny of any differences in learning between gender and the best that could be achieved was to ensure that balance across groups would avoid any skew that gender might have on group results, though the gender effect needs further exploration generally.

A more obvious limitation is that the KLS study is positioned in an Irish education context and tested only in the Irish education system. Although several secondary schools nationally were invited to participate, the uptake was not what was hoped, although entirely understandable given the circumstances of the Covid-

19 pandemic at that time (as can be seen from the date range that the majority of experiments were conducted within). It is possible that other factors led to schools declining the invite due to a lack of resources although none were communicated to the researchers. For example, Chrome books are commonly used in secondary schools, but these do not automatically come with an MS Office software package and would present an additional subscription cost to a school. Some secondary teachers requested the lesson video to be provided in MP4 or Screencast format also as YouTube is not enabled for their students and this highlights concerns for online safety that schools must accommodate. It is possible that the fully online nature of the study and remote return of student results may have been off-putting to some schools for the same reason or for concerns around GDPR, regardless of assurances of anonymity and safe storage of data. Two recommendations arising from this are to repeat KLS testing in more secondary schools nationally after a campaign to raise awareness of its authenticity; and extend the study to international second and third level institutes using the current set of KL lessons.

What could also be considered a limitation is the high level of trust that was expected of students and teachers to comply with the parameters of the study during participation. It was possible for students to cheat by referring to the previous lesson slide when completing tasks, but it was highlighted repeatedly in emails and PowerPoints that a student's academic abilities were not being tested, but rather that the KL approaches were being tested. The correlation analysis provides evidence that students were very compliant with study parameters and the one student whose results returned much higher grades for poorer assembly, presented as an obvious contradiction to every other student who participated. Hence, they were easy to identify and removed accordingly. Another undergraduate student in one of the experiments was easy to identify as having cheated as they typed in highly scientific names for some of the proteins produced by the Lac genes in answer to some of the simple recall questions but failed to answer the remainder of questions in the test. This proved the value having a robust examination of content via the quizzes and at two time-points. That student's results were also removed from analysis.

Experiment 4 was the first large two-timepoint study and did not run as smoothly as experiment 3. Cognitive overload may have impacted learning as several extra slides were introduced which had far more instructions than in previous or subsequent experiments. The addition of an extra task slide also appears to have

been problematic, judged by returned PowerPoints showing that some students in the Unguided Assembly and Guided Assembly groups who had otherwise performed well in assembling tasks, made little attempt to complete the final task or assembled it poorly. This, despite the fact that the Guided Assembly group had guided assembly. There was a general lack of compliance to the timing of the study but the Question Guided Recall group took an inordinately long time to return PowerPoints, hours after the study session was due for completion. This can be attributed to poor control of the study and implementation in subsequent studies was more tightly controlled as a consequence. The presentation of lesson slides also returned to the previous format used in experiment 3, with removal of the extra task slide and instructions. Caution was advised in interpreting the results of experiment 4 because of these issues.

12.6 Impact of Emergent Developments

Emergent developments from the KLS study included the creation of two reliable grading rubrics: one for assessing the lac operon SAQ and the assembly rubric which can quantify visual data quickly as outlined already. The lac operon SAQ is suitable for independent grading by more than one assessor and is less ambiguous than the common use of 'idea units.' This SAQ rubric could also be applied flexibly to a mix of knowledge and transfer questions, to assess both recall and depth of understanding. The assembly rubric was especially effective in quickly quantifying assembly which could then be subjected to a correlation analysis. This would not have been possible to do quickly, or by one assessor, without the assembly rubric. There is great scope for this rubric to become a staple in future research of visual or modelled data. A robust marking scheme was developed to assign partial marks to multi-select exams and this is different to what currently exists for grading MSQs. As with the SAQ rubric, the marking scheme is suitable to apply to a mix of different question types in a single exam, including knowledge and transfer questions in both MCQ and MSQ formats. This provides more flexibility to the researcher/educator to truly challenge learning, concept development and the student's ability to hypothesise. The development of the bespoke lesson video was also highly novel as already discussed in detail.

Although very time-consuming to develop, the Concept Table achieved something unusual in that it facilitated the break-down of an advanced science lesson (the Lac Operon) into its component parts. As an exercise alone, the concept table made this researcher more aware of assumptions held regarding what a student should know in terms of science terminology and prior knowledge, based on this researcher's own familiarity with the language of science. Producing the concept table helped to remove those assumptions by honing in on what the key concepts were and what prior knowledge was necessary to acquire those concepts, what the related key molecules and their functional roles were and what information was most pertinent to support learning and understanding of the key concepts. In doing so, it became easier to recognise extraneous information for removal and helped to reduce any confounding grammar. Consequently, the KL lessons were written in an almost technical style, with the stepwise introduction of key concepts and all illustrations aligned with the key concepts. Thus, the concept table may prove a useful tool for other educators, or researchers who are creating lesson content, to help construct science lessons that are more relevant, impactful for learning and engaging for learners.

The compatibility of the Mental Assembly condition to Unguided Assembly was unexpected and may potentially provide an alternative for those who have physical impairments that reduce or negate online interactions (Gardner, 2013). Above all, the suitability of the Unguided Assembly approach for use as a neutral classroom tool is promising in that certain concepts that a student is struggling with can be pinpointed or serve to flag a student who is struggling overall. In particular, the Unguided Assembly approach enables students to demonstrate their learning and progression in a format that does not rely solely on writing abilities.

12.7 Research Impact for Teaching and Learning

Both the lesson on DNA transcription and on the Lac Operon are universally relevant topics for science learning and as evidenced by the KLS experiments, are suitable for use in the classroom, or remotely for self-directed learning. Hence, the KL lessons can be used immediately by the educator in their current format, with minor changes to the instruction slides as appropriate to the educator's timetable. Because the KL lessons are designed for independent use by the students, there is no

need for teachers to adjust their teaching methods. A teacher could choose, for example, to have the students complete the lesson synchronously in class which would place the teacher in a more supervisory role during the lesson; or it could be given as an asynchronous lesson to introduce students to the topic prior to covering it in class. The latter would support the well-established flipped classroom approach to learning.

Teachers do not require major technical skills to insert the KL lessons, study approaches and online quizzes into the science curriculum beyond what would be expected, i.e., email and PowerPoint are standard online tools in schools and universities. Furthermore, feedback from students and educators alike was positive overall for the format and delivery of the KL lessons, with one teacher requesting permission to continue using the DNA Research Lesson for their school going forward. The interest shown in the highly illustrated format of the KL lessons appears to tap into something highlighted by other researchers who propose that visually dynamic content can support better mental modelling (Seel, 2017; Schneider et al, 2018; Xie et al., 2018). The icons of the KLS are pictorial rather than schematic so they work well toward simplifying some of the more abstract concepts. There is clearly an appetite in academia, beyond research, to improve how science content is engaged with and this is also the likely reason why some learning models and even some neuromyths continue to proliferate (Sharp et al., 2008).

If using the KLS framework as a guide to build KL lessons from new, then there is more of a challenge for the educator to overcome. One of the limitations listed on pg. 206, was the need for a high degree of technical and art sills to create the KL lessons to the level of their current format. The same applies for creating the bespoke videos. This reflects the challenge that other researchers such as Gegner and colleagues (2009) have faced in developing online content for education research. They point out that costs can be an issue, but the time that it takes to generate content is perhaps the most inhibitive factor. However, the workload for others has been reduced significantly through the provision of the KLS framework and list of criteria, to guide the identification, translation and development of an online KL approach. The software has been scoped, technical difficulties overcome and student feedback gathered to ensure the KL lesson format is appropriate and practical for use in further research or directly by the educator at second and third level.

Creating bespoke lessons using the KLS framework also opens up an opportunity for collaboration between a school or a college's art and science departments. Alternatively, there are free websites such as Biorender which facilitate scientific illustration and which could provide basic icons for the purpose of building different biomolecular scenarios when time is more restricted. There are mixed results in research relating to the effectiveness of drawing activities on learning as found by Wu and Rau in their 2019 review, despite the high level of creativity which according to Bloom's taxonomy, demonstrates the highest form of learning and understanding. Perhaps it's a cognitive burden on students to create content if they are uncertain about a concept. The KLS contributes a solution here by enabling students to interact with icons creatively to assemble and explore multiple 'what if' scenarios and to generate visual models, without requiring any art skills. Wu & Rau also discuss how drawing is effective for learning if used to construct new knowledge from prior knowledge and that students who trace over images or copy them, learn less (instance-based training). Prior knowledge was not necessary when using the KL lessons and the Unguided Assembly, which is akin to instance-based training, proved that students could construct new knowledge even when assembly was guided in this approach.

In relation to the quiz which completes the KL lesson, it would be for the educator to decide whether they would retain the quiz in Google Forms or not. They might want to adapt it to run on the school's own LMS, whether that is Google Classrooms in a secondary school, Canvas or Blackboard if it's at third level. The quiz can be delivered on paper if necessary, but this would lack the benefit of keeping the quiz online as a part of the formative assessment and feedback element that enables a student to self-test, practice repeatedly and build their understanding.

For the educator, the KL lesson layout facilitates a rapid, at-a-glance overview for how well individual students are grasping lesson concepts if using an Unguided Assembly or Mental Assembly approach. This KLS research has demonstrated that constructive alignment of learning outcomes to teaching and learning activities and assessments for the KL lessons and tasks is suitable for integrating into mainstream academia at multiple levels. The various KL assembly approaches (Guided, Unguided and Mental) have proven predictive validity for grade outcome, making them a reliable measure for use by researchers and educators, although further testing using larger sample sizes is recommended. The most interesting contribution

to research and education for this study, is the unique finding that Unguided Assembly correlates strongly with grade outcome. Therefore, there are many further avenues to explore with this KL assembly model. Other impactful findings from this study to be cognisant of when planning online teaching or learning activities are as follows:

- Confirmed a 'methods' effect on learning and contradicted a 'media' effect.
- Observed a 'skimming' effect.
- Contradicted the ICAP framework that memorisation is an LOCS.
- Demonstrated a 'cramming' effect for active memorisation with the Neutral study condition.

In summary, the KLS provides a very agile framework to support other researchers and educators in identifying, translating and developing KL approaches for advanced science topics into online, interactive and engaging lessons. Furthermore, the strategy to test the KLS as realistically as possible has resulted in the creation of a framework and online lesson format that is highly adaptable, reproducible and assessable, in a manner not currently met in education. For researchers, the KLS framework, interactive KL lessons and assessments are open for adaptation, improvement and collaboration opportunities.

12.8 A Summary of Recommendations

A number of recommendations arise from this study and may be summarised as follows:

- Explore science illustration in the frame of the KLS for visual modelling to enhance students' mental image processing, encourage creativity and disseminate science to a broader audience.
- Investigate the role of pre-lecture videos in improving science learning within the format of the KLS framework.
- Test the KL assembly model using greater sample sizes and amongst other disciplines to optimise and reveal more potential applications of the model.
- Test the Mental Assembly approach among physically impaired students who could benefit from its potential.

- Repeat KLS testing in more second-level and third-level institutions nationally and internationally, using the current set of KL lessons and in comparison to KL lessons on different topics.
- Incorporate KL lesson icons into exams to create a more visual question format to test transfer knowledge. For example, instead of writing a question about a hypothetical scenario (e.g., changing the order of genes), present the scenario visually using the KL lesson icons and ask the student to predict the outcome of such an arrangement.
- Revisit the use of the Concept Table to optimise its use as a tool for educators to remove confounding factors from science lessons and to improve communication of the key concepts.

12. Closing Remarks

The idea for this research emerged from the observation that science at a molecular level could not be visibly interacted with for learning on platforms that were inexpensive, adaptable or agile for scalable use, or to suit different levels of knowledge. At a molecular level, science reveals a universe of invisible molecules that students must utilise their powers of imagination to form mental images of a nano world. Unseen atoms layer into molecules and compounds, undergoing hectic chemical reactions that proceed at a speed and in a manner beyond our everyday sensory awareness. Not all steps or molecules of a biochemical process may be known, but students of science will endeavour to learn the hypothesised and the theoretical, along with the unknown. The baton is passed to every new generation of graduates to continue plugging the knowledge gaps with research that is ethical and honestly reported.

Motivation is an important feature of progressing learning and maintaining student engagement (Quillin & Thomas, 2015). Accordingly, the most important stakeholders in this study were the students and their voice was taken seriously when analysing and re-evaluating all aspects of the KL lesson, tasks and delivery. Student feedback was very constructive and positive overall, especially in light of having to learn an academically advanced topic. Many students expressed interest in participating in future KLS related studies and commented optimistically on the novelty of the KL lesson approaches for learning science. Both the qualitative and quantitative data validate this thesis hypothesis to be true: online kinaesthetic

approaches are highly effective in grasping new science concepts, for understanding advanced biomolecular processes and for enhancing long-term knowledge retention.

> *"In qualitative methodologies, reliability includes fidelity to real life, context-and situation-specificity, authenticity, comprehensiveness, detail, honesty, depth of response and meaningfulness to the respondents."*
> *(Cohen et al., 2007, p.79)*

"I admire your work and the changes you're trying to bring about for us students, hope it all goes well in the future." – Student

References

Adams NE. Bloom's taxonomy of cognitive learning objectives. J Med Libr Assoc. 2015 Jul;103(3):152-3. doi: 10.3163/1536-5050.103.3.010. PMID: 26213509; PMCID: PMC4511057.

Ahmed, V., & Opoku, A. (2021). Technology supported learning and pedagogy in times of crisis: the case of COVID-19 pandemic. *Educ Inf Technol* (Dordr), 1-41. https://doi.org/10.1007/s10639-021-107 06-w

American Psychological Association. (2020). *Publication manual of the American Psychological Association* (7th ed.). https://doi.org/10.1037/0000165-000

Baskaran G, Applanaidu B, Ng PK, Ramakrishnan K (2015). Moodle good learning environment? Survey to Support Lecturers in Identifying VARK Learning Styles and Students Learning Experiences. *Proceedings of the Multidisciplinary Academic Conference:*1-6.

Bédécarrats, A., Chen, S., Pearce, K., Cai, D., & Glanzman, D. L. (2018). RNA from Trained Aplysia Can Induce an Epigenetic Engram for Long-Term Sensitization in Untrained Aplysia . *ENeuro*, *5*(3). https://doi.org/10.1523/ENEURO.0038-18.2018

Bell V, Bishop DVM, Przybylski AK (2015) The debate over digital technology and young people. BMJ (Clinical Research Ed) 351:h3064-h3064.

Bétrancourt, M., & Benetos, K. (2018). Why and when does instructional video facilitate learning? A commentary to the special issue “developments and trends in learning with instructional video”. *Computers in Human Behavior*, *89*, 471-475. https://doi.org/https://doi.org/10.1016/j.chb.2018.08.035

Biggs, J.B. (2003). *Teaching for quality learning at university*. Buckingham: Open University Press/Society for Research into Higher Education. (Second edition)

Birkett, A. (2019). One-Tailed vs. Two-Tailed Tests (Does It Matter?). https://cxl.com/blog/one-tailed-vs-two-tailed-tests/

Bloom, J. (2007). (Mis)reading Social Class in the Journey towards College: Youth Development in Urban America. Teachers College Record, 109(2), 343–368. https://doi.org/10.1177/016146810710900201

Bolliger, D. U., & Supanakorn, S. (2011). Learning styles and student perceptions of the use of interactive online tutorials [Article]. *British Journal of Educational*

Technology, 42(3), 470-481. https://doi.org/10.1111/j.1467-8535.2009.01037.x

Brame, C. J., & Biel, R. (2015). Test-enhanced learning: the potential for testing to promote greater learning in undergraduate science courses. *CBE Life Sci Educ*, *14*(2), 14:es14. https://doi.org/10.1187/cbe.14-11-0208

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77-101. https://doi.org/10.1191/1478088706qp063oa

Bree, R. (2018). *Embracing alternative formats, assessment strategies and digital technologies to revitalise practical sessions in Science & Health* (A. Akande, D. Brazil, D. Doyle, N. Harding, Y. Kavanagh, M. Maguire, & A. Mulvihill, Eds.; 1st ed.). TEAM Project Publication. https://www.teamshp.ie/wp-content/uploads/2011/09/Bree-2018-TEAM-Literature-rev-report_Web.pdf

Brumpton, K., Kitchener, S., & Sweet, L. (2013). Learning styles in vertically integrated teaching [Article]. *Clinical Teacher*, 10(5), 282-286. https://doi.org/10.1111/tct.12024

Bui, D. C., Myerson, J., & Hale, S. (2013). Note-taking with computers: Exploring alternative strategies for improved recall. *Journal of Educational Psychology*, 105(2), 299-309. https://doi.org/10.1037/a0030367

Camina, E., & Güell, F. (2017). The Neuroanatomical, Neurophysiological and Psychological Basis of Memory: Current Models and Their Origins [Review]. *Frontiers in Pharmacology*, 8. https://doi.org/10.3389/fphar.2017.00438

Camfield, E.K., McFAll, E.E, Land, K.M., (2016). Leveraging Innovation in Science Education: Using Writing and Assessment to Decode the Class Size Conundrum. *Liberal Education*, 101/102, 64.

Carr, N. G. (2011). *The shallows: what the Internet is doing to our brains.* Norton pbk. [ed.] New York: W.W. Norton.

CAST (2018). Universal Design for Learning Guidelines version 2.2. Retrieved from http://udlguidelines.cast.org

Caulfield, J. (2022, November 25). *How to Do Thematic Analysis | Step-by-Step Guide & Examples*. Scribbr. https://www.scribbr.com/methodology/thematic-analysis/

Cherry, K. (Oct 2022). *What is Long-Term Memory?* VeryWellMind. https://www.verywellmind.com/what-is-long-term-memory-2795347?

Chesley, N. (2005). Blurring Boundaries? Linking Technology Use, Spillover, Individual Distress, and Family Satisfaction. *Journal of Marriage and Family*, 67(5), 1237-1248. https://doi.org/https://doi.org/10.1111/j.1741-3737.2005.00213.x

Chi, M. T. H., & Wylie, R. (2014). The ICAP Framework: Linking Cognitive Engagement to Active Learning Outcomes. *Educational Psychologist*, 49(4), 219-243. https://doi.org/10.1080/00461520.2014.965823

Clark, R. C., & Mayer, R. E. (2008). *E-Learning and the science of instruction : proven guidelines for consumers and designers of multimedia learning* (2nd ed.). Pfeiffer.

Clark, R. E. (1994). Media Will Never Influence Learning. *Educational Technology Research and Development*, *42*(2), 21–29. http://www.jstor.org/stable/30218684

Co, E. (2019). The Power of Practice: Adjusting Curriculum to Include Emphasis on Skills. *Journal of College Science Teaching*, *48*(5), 22–27. https://www.jstor.org/stable/26901312

Cohen, L., Manion, L., & Morrison, K. (2007). *Research Methods in Education* (6th ed.). London and New York, NY: Routledge Falmer.

Cortes, R.A., Peterson, E.G., Kraemer, D.J., Kolvoord, R.A., Uttal, D.H., Dinh, N., Weinberger, A.B., Daker, R.J., Lyons, I.M., Goldman, D., & Green, A.E. (2022). Transfer from spatial education to verbal reasoning and prediction of transfer from learning-related neural change. *Science Advances, 8*.

Costa, R. O., Martins, L. F., Tahiri, E., & Duarte, C. B. (2022). Brain-derived neurotrophic factor-induced regulation of RNA metabolism in neuronal development and synaptic plasticity. *Wiley Interdisciplinary Reviews: RNA*, 13(5), e1713. https://doi.org/10.1002/wrna.1713

Costabile, M. (2020). Using online simulations to teach biochemistry laboratory content during COVID-19. *Biochem Mol Biol Educ*. 2020; 48: 509– 510. https://doi.org/10.1002/bmb.21427

Crossman, A. R., & Neary, D. (2015). *Neuroanatomy: An Illustrated Colour Text*. Churchill Livingstone Elsevier. ISBN: 0443044791

Cuevas, J. (2016). An analysis of current evidence supporting two alternate learning models: Learning styles and dual coding. *Journal of Educational Sciences and Psychology*, 6(1), 1-13.

Curtin, E. (2020). *UCCSU Student Feedback on Online Learning Report Published* | UCC Students Union. https://www.uccsu.ie/uccsu-student-feedback-on-online-learning-report-published/

Domangue, T. J., et al. (2004). Effects of model-based and memory-based processing on speed and accuracy of grammar string generation. *Journal of Experimental Psychology, 30(5),* 1002–1011.

Dommett, E. J., Devonshire, I. M., Plateau, C. R., Westwell, M. S., & Greenfield, S. A. (2011). From scientific theory to classroom practice. *Neuroscientist*, 17(4), 382-388. https://doi.org/10.1177/1073858409356111

De Jong T (2010) Cognitive load theory, educational research, and instructional design: some food for thought. *Instructional Science* 38:105-134.

European Cooperation in Science and Technology (COST). (2019). *COST E-READ Stavanger Declaration Concerning the Future of Reading*. Frankfurter Allgemeine Zeitung. https://ereadcost.eu/stavanger-declaration/

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39, 175-191. [PDF]

Fiorella, L., & Mayer, R. E. (2018). What works and doesn't work with instructional video. *Computers in Human Behavior*. https://doi.org/10.1016/j.chb.2018.07.015

Fiorella, L., van Gog, T., Hoogerheide, V., & Mayer, R. E. (2017). It's all a matter of perspective: Viewing first-person video modeling examples promotes learning of an assembly task. *Journal of Educational Psychology*, 109(5), 653-665. https://doi.org/10.1037/edu0000161

Firth, J., Torous, J., Stubbs, B., Firth, J. A., Steiner, G. Z., Smith, L., . . . Sarris, J. (2019). The "online brain": how the Internet may be changing our cognition. *World Psychiatry*, 18(2), 119-129. https://doi.org/10.1002/wps.20617

Fleming, N.D. and Mills, C. (1992), Not Another Inventory, Rather a Catalyst for Reflection. *To Improve the Academy*, 11: 137-155. https://doi.org/10.1002/j.2334-4822.1992.tb00213.x

Gagnier, K. M., Atit, K., Ormand, C. J., & Shipley, T. F. (2016). Comprehending diagrams: sketching to support spatial reasoning. Topics in Cognitive Science, 1–19. https://doi.org/10.1111/tops.12233

Gamage, K. A. A., & Perera, E. (2021). Undergraduate Students' Device Preferences in the Transition to Online Learning. *Social Sciences*, *10*(8).

Gardner, H. E. (1999). *Intelligence Reframed: Multiple Intelligences For The 21st Century.* Basic Books.

Gardner, H.E. (2013). Frequently asked questions—multiple intelligences and related educational topics. http://www.pz.harvard.edu/sites/default/files/faq.pdf

Gazzaniga, M. S. (Ed.). (2000). *The New Cognitive Neurosciences* (2nd ed.). The MIT Press.

Gegner, J., Mackay, D., & Mayer, R. (2009). Computer-supported aids to making sense of scientific articles: cognitive, motivational, and attitudinal effects [Article]. *Educational Technology Research & Development*, 57(1), 79-97.https://doi.org/10.1007/s11423-008-9088-3

Gillan, C. M., et al. (2015). Model-based learning protects against forming habits. *Cognitive, Affective, and Behavioral Neuroscience, 15(3),* 523–536.

Girvan, C., Conneely, C., & Tangney, B. (2016). Extending experiential learning in teacher professional development. *Teaching and Teacher Education*, *58*, 129-139. https://doi.org/https://doi.org/10.1016/j.tate.2016.04.009

Glavin, C. (2017, February 12). *High School Education in Romania*. High School Education in Romania | K12 Academics. https://www.k12academics.com/Education%20Worldwide/Education%20in%20Romania/high-school-education-romania

Goswami, U. (2006). Neuroscience and education: from research to practice? *Nature Reviews Neuroscience*, 7(5), 406-413. https://doi.org/10.1038/nrn1907

Greenfield, S. (2003). *Tomorrow's people : how 21st century technology is changing the way we think and feel*. Allen Lane.

Greenfield, S. (2015). *Mind Change: How Digital Technologies Are Leaving Their Mark on Our Brains*. Random House Publishing Group.

Halpern, D. F., & Hakel, M. D. (2003). Applying the Science of Learning to the University and Beyond: Teaching for Long-Term Retention and Transfer. *Change: The Magazine of Higher Learning*, 35(4), 36-41. https://doi.org/10.1080/00091380309604109

Harlen, W. (n.d.) Issues in policy and practice in the assessment of inquiry-based science education. https://www.dcu.ie/sites/default/files/smec/pdfs/WHarlen-issues-in-policy-and-practice-assessment-of-inquiry-based-science-education.pdf

Haughton C, Aiken M, Cheevers C (2015) Cyber Babies: The Impact of Emerging Technology on the Developing Infant. *Psychology Research*, 5(9), 504-518. doi.10.17265/2159-5542/2015.09.002

Hayashi, Y. (2022). Molecular mechanism of hippocampal long-term potentiation – Towards multiscale understanding of learning and memory. *Neuroscience Research*, 175, 3-15. Doi.10.1016/j.neures.2021.08.001

Hazeltine, E., & Ivry, R. (2002). Motor Skill. In V. S. Ramachandran (Ed.), *Encyclopedia of the Human Brain* (pp. 183-200). Academic Press. https://doi.org/10.1016/B0-12-227210-2/00219-3

Heyes, C., & Catmur, C. (2022). What Happened to Mirror Neurons? *Perspectives on Psychological Science*, 17(1), 153–168. https://doi.org/10.1177/1745691621990638

Hill, C., Corbett, C., & St. Rose, A. (2010). Why So Few? Women in Science, Technology, Engineering, and Mathematics. *American Association of University Women*.

Jamieson, D. W., & Thomas, K. W. (1974). Power and Conflict in the Student-Teacher Relationship. *The Journal of Applied Behavioral Science*, 10(3), 321–336. https://doi.org/10.1177/002188637401000304

Kandel, Eric R., Dudai, Y., & Mayford, Mark R. (2014). The Molecular and Systems Biology of Memory. *Cell*, 157(1), 163-186. https://doi.org/10.1016/j.cell.2014.03.001

Karpicke, J. D., & Blunt, J. R. (2011). Retrieval practice produces more learning than elaborate studying with concept mapping. *Science*, *331*(6018), 772-775. https://doi.org/10.1126/science.1199327

Kennedy, D. (2006) *Writing and using learning outcomes: a practical guide*, Cork: University College Cork.

Kennedy, J. (2022). Leaving Cert 2022: what is really best for Irish students? *Farmers Journal*. https://www.farmersjournal.ie/leaving-cert-2022-what-is-really-best-for-irish-students-678178

IBM Corp. Released 2020. IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY: IBM Corp

Kogl Camfield, E. E. M., Eileen, Pacific, U. o. t., Land, K. M., & Pacific, U. o. t. (2016). Leveraging Innovation in Science Education: Using Writing and Assessment to Decode the Class Size Conundrum. *Liberal Education*, 101/102, 64.

Kolb, B., & Whishaw, I. Q. (1996). *Fundamentals of Human Neuropsychology* (4th ed.). W.H. Freeman and Company.

Korbach, A., Brünken, R., & Park, B. (2016). Learner characteristics and information processing in multimedia learning: A moderated mediation of the seductive details effect. *Learning and Individual Differences*, *51*, 59-68. https://doi.org/https://doi.org/10.1016/j.lindif.2016.08.030

Kukushkin, N. V., Tabassum, T., & Carew, T. J. (2022). Precise timing of ERK phosphorylation/dephosphorylation determines the outcome of trial repetition during long-term memory formation. *Proceedings of the National Academy of Sciences*, 119(40), e2210478119. https://doi.org/10.1073/pnas.2210478119

Kumar, A., Sarkar, M., Davis, E., Morphet, J., Maloney, S., Ilic, D., & Palermo, C. (2021). Impact of the COVID-19 pandemic on teaching and learning in health professional education: a mixed methods study protocol. *BMC Medical Education*, 21(1), 439. https://doi.org/10.1186/s12909-021-02871-w

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs [Review]. *Frontiers in Psychology*, *4*. https://doi.org/10.3389/fpsyg.2013.00863

LeDoux, J. E. (2002). Synaptic self : how our brains become who we are. Viking.

Leisman, G., Moustafa, A. A., & Shafir, T. (2016). Thinking, Walking, Talking: Integratory Motor and Cognitive Brain Function [Review]. *Frontiers in Public Health*, 4. doi: 10.3389/fpubh.2016.00094.

Linn, R. L. (2000). Assessments and Accountability. *Educational Researcher*, *29*(2), 4-16. https://doi.org/10.3102/0013189X029002004

Liu, Y., Meng, X. & Roy-Campbell, Z. The modality and redundancy principles revisited: do they apply in a controlled multimedia lesson?. *J Comput High Educ* (2022). https://doi.org/10.1007/s12528-022-09329-y

Looney, J. (2009), "Assessment and Innovation in Education", *OECD Education Working Papers*, No. 24, OECD Publishing, Paris, https://doi.org/10.1787/222814543073

Madaus, G., Russell, M. (2010). Paradoxes of high-stakes testing. *Journal of Education*, 190 (1/2), 21-30.

Madigan, M. T., Martinko, J. M., Dunlop, P. V., & Clark, D. P. (2009). *Brock Biology of Microorganisms 12th Edition*.

Makransky, G., & Petersen, G. B. (2021). The Cognitive Affective Model of Immersive Learning (CAMIL): a Theoretical Research-Based Model of

Learning in Immersive Virtual Reality. *Educational Psychology Review*, 33(3), 937-958. https://doi.org/10.1007/s10648-020-09586-2

Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2019). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and Instruction*, 60, 225-236. https://doi.org/10.1016/j.learninstruc.2017.12.007

Mark, G., Iqbal, S.T., Czerwinski, M & Johns, P. (2014). Bored mondays and focused afternoons: the rhythm of attention and online activity in the workplace. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14). *Association for Computing Machinery*, New York, NY, USA, 3025–3034. https://doi.org/10.1145/2556288.2557204

Masicampo, E. J., & Lalande, D. R. (2012). A peculiar prevalence of p values just below .05. *Quarterly journal of experimental psychology (2006)*, *65*(11), 2271–2279. https://doi.org/10.1080/17470218.2012.711335

Mason, L., Lowe, R., & Tornatora, M. C. (2013). Self-generated drawings for supporting comprehension of a complex animation. Contemporary Educational Psychology, 38(3), 211–224. https://doi.org/10.1016/j.cedpsych.2013.04.001

Mayer, R. E. (2003). The promise of multimedia learning: using the same instructional design methods across different media [Article]. *Learning & Instruction*, 13(2), 125. https://doi.org/10.1016/S0959-4752(02)00016-6

Mayer, R. E. (2018). Educational psychology's past and future contributions to the science of learning, science of instruction, and science of assessment. *Journal of Educational Psychology*, 110(2), 174-179. https://doi.org/10.1037/edu0000195

Mayer, R. E., Hegarty, M., Mayer, S., & Campbell, J. (2005). When static media promote active learning: annotated illustrations versus narrated animations in multimedia instruction. J *Exp Psychol Appl*, 11(4), 256-265. https://doi.org/10.1037/1076-898x.11.4.256

McCoy, B. R., (2016). Digital Distractions in the Classroom Phase II: Student Classroom Use of Digital Devices for Non-Class Related Purposes. *Journal of Media Education* Vol. 7 Iss. 1 (2016) p. 5 - 32. http://digitalcommons.unl.edu/journalismfacpub/90

McGrath, C., Palmgren, P. J., & Liljedahl, M. (2019). Twelve tips for conducting qualitative research interviews. *Medical teacher*, *41*(9), 1002–1006. https://doi.org/10.1080/0142159X.2018.1497149

McLeod, S. A. (2015). *Cognitive psychology*. Simply Psychology. www.simplypsychology.org/cognitive.html

McLeod, S. A. (2016, February 05). *Bandura - social learning theory*. Simply Psychology. www.simplypsychology.org/bandura.html

McLeod, S. A. (2017a, Febuary 05). *Behaviorist approach*. Simply Psychology. www.simplypsychology.org/behaviorism.html

McLeod, S. A. (2017b, October 24). *Kolb - learning styles*. Simply Psychology. http://www.simplypsychology.org/learning-kolb.html

McLeod, S. A. (2018a, January, 21). *Skinner - operant conditioning*. Simply Psychology. http://www.simplypsychology.org/operant-conditioning.html

McLeod, S. A. (2018b, October 08). *Pavlov's dogs*. Simply Psychology. www.simplypsychology.org/pavlov.html

McLeod, S. A. (2019, July 17). *Constructivism as a theory for teaching and learning*. Simply Psychology. www.simplypsychology.org/constructivism.html

Minarechová, M. (2012). Negative impacts of high-stakes testing. *Journal of Pedagogy, 3*(1), 82-100. https://doi.org/doi:10.2478/v10159-012-0004-x

Newcomer, J. W., Farber, N. B., & Olney, J. W. (2000). NMDA receptor function, memory, and brain aging. *Dialogues in Clinical Neuroscience*, 2(3), 219-232. https://doi.org/10.31887/DCNS.2000.2.3/jnewcomer

Newton, P. M., Najabat-Lattif, H. F., Santiago, G., & Salvi, A. (2021). The Learning Styles Neuromyth Is Still Thriving in Medical Education. *Front Hum Neurosci,* 15, 708540. https://doi.org/10.3389/fnhum.2021.708540

Nguyen JD, Duong H. Neurosurgery, Sensory Homunculus. [Updated 2023 Jul 24]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK549841/

Oakley, B., Sejnowski, T. (n.d.). *Learning How to Learn: Powerful mental tools to help you master tough subjects.* [MOOC]. Coursera. https://www.coursera.org/learn/learning-how-to-learn

O'Brien, M. (2008) Wellbeing and Post-Primary Schooling: A review of the Literature. Dublin: NCCA

O'Day, G. M., & Karpicke, J. D. (2021). Comparing and combining retrieval practice and concept mapping. *Journal of Educational Psychology, 113*(5), 986-997. https://doi.org/10.1037/edu0000486

O'Leary, D. D. (1992). *Curr. Opin. Neurobiol.* 2:70-77

O'Reilly, T., Symons, S., & MacLatchy-Gaudet, H. (1998). Brief research report: A comparison of self-explanation and elaborative interrogation. *Contemporary Educational Psychology, 23*, 434–445. [PubMed]

Oppenheim, R. W. (1998). In *Fundamental Neuroscience*, edited by M. Zigmond. San Diego: Academic Press.

Pallant, J. (2011). *SPSS SURVIVAL MANUAL A step by step guide to data analysis using SPSS* (4th ed.). Allen & Unwin. (2002)

Papadatou-Pastou, M., Gritzali, M., & Barrable, A. (2018). The Learning Styles Educational Neuromyth: Lack of Agreement Between Teachers' Judgments, Self-Assessment, and Students' Intelligence [Brief Research Report]. *Frontiers in Education*, 3.

Pappas, C. (2013). The Adult Learning Theory – Andragogy – of Malcolm Knowles. Elearningindustry.com. [http://www.elearningindustry.com/the-adult-learning-theory-andragogy-of-malcolm-knowles. Retrieved: 2021]

Price, P. C., Jhangiani, R., Chiang, I.-C. A., Leighton, D. C., & Cuttler, C. (2022). *Research Methods in Psychology*. PRESSBOOKS. https://opentext.wsu.edu/carriecuttler/chapter/13-1-understanding-null-hypothesis-testing/

Pulvermüller, F., Härle, M., & Hummel, F. (2001). Walking or Talking?: Behavioral and Neurophysiological Correlates of Action Verb Processing. *Brain and Language*, 78(2), 143-168. https://doi.org/10.1006/brln.2000.2390

QSR International Pty Ltd. (2020) NVivo (released in March 2020), https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home

Quillin, K., & Thomas, S. (2015). Drawing-to-learn: a framework for using drawings to promote model-based reasoning in biology. *CBE life sciences education*, 14(1), es2. https://doi.org/10.1187/cbe.14-08-0128

Rakic, P., Bourgeois, J.-P., Eckenhoff, M. F., Zecevic, N., & Goldman-Rakic, P. S. (1986). Concurrent Overproduction of Synapses in Diverse Regions of the Primate Cerebral Cortex. *Science*, 232(4747), 232-235. https://doi.org/10.1126/science.3952506

Rawson, K. A., & Kintsch, W. (2005). Rereading effects depend on time of test. Journal of Educational Psychology, 97, 70 – 80. doi:10.1037/ 0022-0663.97.1.70

Roediger, H. L., & Karpicke, J. D. (2006). Test-Enhanced Learning:Taking Memory Tests Improves Long-Term Retention. *Psychological Science, 17*(3), 249-255. https://doi.org/10.1111/j.1467-9280.2006.01693.x

Rohmann, J., (27th April 2018). Confidence intervals should be reported. https://s4be.cochrane.org/blog/2018/04/27/confidence-intervals-should-be-reported/

Runco, M. A., & Abdullah, A. M. (2014). Why isn't creativity being supported? Distressing analyses of grants and awards for creativity research–or lack thereof. *Creativity Research Journal*, *26*(2), 248–250. https://doi-org.ucc.idm.oclc.org/10.1080/10400419.2014.901100

Sankey, M. D., Birch, D., & Gardiner, M. W. (2011). The impact of multiple representations of content using multimedia on learning outcomes across learning styles and modal preferences [Article]. *International Journal of Education & Development using Information & Communication Technology*, 7(3), 18-35.

Scanlan, A. M., Kennedy, D., & McCarthy, T. V. (2021). Development and Evaluation of Online Approaches for Improved Kinaesthetic Learning in Science. *7th International Conference on Higher Education Advances* (HEAd'21), Val`encia. http://dx.doi.org/10.4995/HEAd21.2021.13146

Schneider, S., Beege, M., Nebel, S., & Rey, G. D. (2018). A meta-analysis of how signaling affects learning with media. *Educational Research Review*, 23, 1-24. https://doi.org/10.1016/j.edurev.2017.11.001

Seel, N. M. (2017). Model-based learning: a synthesis of theory and research. *Educational Technology Research and Development*, 65(4), 931-966. https://doi.org/10.1007/s11423-016-9507-9

Shabatura, J. (Jul 26, 2022). *Using Bloom's Taxonomy to Write Effective Learning Outcomes* [Blog]. https://tips.uark.edu/using-blooms-taxonomy/

Sharp, J. G., Bowker, R., & Byrne, J. (2008). VAK or VAK-uous? Towards the trivialisation of learning and the death of scholarship. *Research Papers in Education*, 23(3), 293-314. https://doi.org/10.1080/02671520701755416

Shute, V. J., Leighton, J. P., Jang, E. E., & Chu, M.W. (2016). Advances in the Science of Assessment. *Educational Assessment*, 21(1), 34-59. https://doi.org/10.1080/10627197.2015.1127752

Slater JA, Lujan HL, DiCarlo SE (2007) Does gender influence learning style preferences of first-year medical students? *Adv Physiol Educ* 31:336-342.

Smith, A. (1998). *Accelerated learning in practice*. A&C Black.

Smith, M.K. (2002) 'Jerome S. Bruner and the process of education', *The encyclopedia of pedagogy and informal education*. [https://infed.org/mobi/jerome-bruner-and-the-process-of-education/ Retrieved: 2021]

Smyth, E., Banks, J., & Calvert, E. (2011). *From Leaving Certificate to Leaving School: A Longitudinal Study of Sixth Year Students | ESRI*. The Liffey Press in association with ESRI, NCCA and Department of Education & Skills.

Sparrow, B., Liu, J., & Wegner, D. (2011). Google effects on memory: Cognitive consequences of having information at our fingertips. *Science*, 333(6043),776

Squire, L.R., Berg, D.K., Bloom, F.E., Lac, S.D., Ghosh, A., & Spitzer, N.C. (2012). *Fundamental Neuroscience* (Fourth ed.). https://doi.org/10.1016/C2010-0-65035-8

Stucchio, C. (2015). One tailed vs two tailed A/B tests - your decision procedure is the deciding factor. *Chrisstucchio.com*. https://www.chrisstucchio.com/blog/2015/one_tailed_and_two_tailed_tests.html

Tawfik, A. A., Reeves, T. D., & Stich, A. (2016). Intended and Unintended Consequences of Educational Technology on Social Inequality. *TechTrends*, *60*(6), 598-605. https://doi.org/10.1007/s11528-016-0109-5

Torgerson, C. J., & Torgerson, D. J. (2001). The Need for Randomised Controlled Trials in Educational Research. *British Journal of Educational Studies*, *49*(3), 316-328. https://doi.org/10.1111/1467-8527.t01-1-00178

Trafton, J. G., & Trickett, S. B. (2001). Note-Taking for Self-Explanation and Problem Solving. *Human–Computer Interaction*, *16*(1), 1-38. https://doi.org/10.1207/S15327051HCI1601_1

Turner, K. L. (2016). A Cost-Effective Physical Modeling Exercise to Develop Students' Understanding of Covalent Bonding. *Journal of Chemical Education*, 93(6), 1073-1080.

Tversky, B., Morrison, J. B., & Betrancourt, M. (2002). Animation: Can it facilitate? *International Journal of Human–Computer Studies, 57,* 247–262.

UNESCO. 2020. *UNESCO Covid-19 Education Response: Education Sector Issue Notes.* Issue Note No 4.3, Paris, May, 2020 [PDF]

Van Aken, K. (2016). The critical role of creativity in research. *MRS Bulletin*, *41*(12), 934-938. doi:10.1557/mrs.2016.280

Van Beusekom, M. (2022, Dec 1). Pandemic online learning stressed college students, teens. *CIDRAP News*, University of Minnesota. Retrieved: 2023 https://www.cidrap.umn.edu/covid-19/pandemic-online-learning-stressed-college-students-teens

Walshe, J. (2021, Sept 08). Points race is far from finished as earlier classes compete with those who got a grade boost. [https://www.independent.ie/irish-news/education/points-race-is-far-from-finished-as-earlier-classes-compete-with-those-who-got-a-grade-boost-40828178.html. Retrieved: 2021]

Watkins, J. C., & Jane, D. E. (2006). The glutamate story. *British Journal of Pharmacology*, 147(S1), S100-S108. https://doi.org/10.1038/sj.bjp.0706444

Weishaar, K. (2021). Reinventing Education Post-Pandemic. https://tll.mit.edu/reinventing-education-post-pandemic/

Wellington, J. J. (2000). *Educational research : contemporary issues and practical approaches*. Continuum.

What Now For STEM - Accenture in Ireland. (2019). https://www.slideshare.net/accenture/what-now-for-stem-accenture-in-ireland

Wilson, T. D., Reinhard, D. A., Westgate, E. C., Gilbert, D. T., Ellerbeck, N., Hahn, C., . . . Shaked, A. (2014). Just think: The challenges of the disengaged mind. *Science*, 345(6192), 75-77. https://doi.org/10.1126/science.1250830

Wimsatt, W. C. (1987). False models as means to truer theories. In M. Nitecki (Ed.), *Neutral models in biology* (pp. 23–55). London: Oxford University Press.

Wu, S.P.W., Rau, M.A. How Students Learn Content in Science, Technology, Engineering, and Mathematics (STEM) Through Drawing Activities. *Educ Psychol Rev* **31**, 87–120 (2019). https://doi.org/10.1007/s10648-019-09467-3

Xie, H., Mayer, R. E., Wang, F., & Zhou, Z. (2019). Coordinating visual and auditory cueing in multimedia learning. *Journal of Educational Psychology*, 111(2), 235-255. https://doi.org/10.1037/edu0000285

Yogev, E., Gal, K., Karger, D., Facciotti, M. T., & Igo, M. (2018). *Classifying and visualizing students' cognitive engagement in course readings* Proceedings of the Fifth Annual ACM Conference on Learning at Scale, London, United Kingdom. https://doi.org/10.1145/3231644.3231648

Zacharopoulos, G., Sella, F., Cohen Kadosh, K., Hartwright, C., Emir, U., Cohen Kadosh, R. (2021). Predicting learning and achievement using GABA and

glutamate concentrations in human development. *PLoS Biol* 19(7): e3001325. https://doi.org/10.1371/journal.pbio.3001325

URL 1: https://dictionary.cambridge.org/dictionary/english/kinaesthetic

URL 2: https://vark-learn.com/using-vark/using-vark-in-research/

URL 3: Image courtesy of "Anatomage Inc. – Anatomage Table EDU." https://www.anatomage.com/image-library/

URL 4: Nickle, T., & Barrette-Ng, I. (n.d.). The lac Operon. Mount Royal University & University of Calgary. Retrieved [2019], from https://bio.libretexts.org/@go/page/4150

URL 5: Case courtesy of Dr Francisco Gallegos, Radiology Quiz 124821 | Radiopaedia.orgViewing playlist: Neuroanatomy Review | Radiopaedia.org rID: 28170

URL 6: PISA scores by country 2023. (n.d.). https://worldpopulationreview.com/country-rankings/pisa-scores-by-country

URL 7: https://readable.com/readability/flesch-reading-ease-flesch-kincaid-grade-level/

URL 8: How codes become themes (Part 2) | Generating thematic framework from Research with Dr Kriukow. https://youtu.be/FTD_xIeYlWU

URL 9: Understanding grading options for multi-select questions. (n.d.). Brightspace. Retrieved [2021], from https://documentation.brightspace.com/EN/le/question_library/instructor/grade_options_for_multi_select.htm

Appendices

Appendix A

Due to the volume of materials used throughout the thesis research, it is not practical to present all materials in these appendices. Further materials are available on request. This section contains sample emails from various experiments, a typical participant information sheet, consent form and participant questionnaire that were given to undergraduate students. Closely similar emails, participant information, consent forms and questionnaires were used in subsequent experiments. Hence, they are only shown once in the appendices.

Figure A.1

Sample Invitation Email

Dear Student,

I am a PhD student in the Schools of Biochemistry and Education in UCC and am looking for all non-science students and early science students (up to 1st year undergraduate biological science) to help with my research.

This research is aimed at developing online interactive learning techniques that will help students to learn complex science topics faster, with less stress and with better long-term recall. Feedback from 2 pilot studies so far has been hugely beneficial to the design and delivery of our lessons. Below are some quotes from early study participants:

"I enjoyed this! It wasn't boring and everything was succinct and to the point. The diagrams made it more fun."

"I admire your work and the changes you're trying to bring about for us students, hope it all goes well in the future."

The main phase of the study is about to begin and I hope to recruit a large number of volunteers from non-biological science backgrounds (students who have not completed a biological science module beyond 1st year undergraduate science).
Volunteering is very simple, will require just an hour of your time and can be done in any location in which you have access to a strong internet connection. You will be asked to study a short online science lesson (11 mins video) and then proceed to using specific on-screen study approaches designed to enhance learning. This study period will be followed by a short multiple-choice question (MCQ) exam, the results of which will be used to identify the most effective study approach.

My work is carried out under the supervision of Prof. Tommie McCarthy (Biochemistry) and Dr. Declan Kennedy (Education). We have given the name "SCIOPTLE - Optimising Learning of Science" to this research initiative. There is a short questionnaire associated with volunteering and in line with approved research ethics, volunteers are required to read key information for participants and complete a consent form.

You can sign up for volunteering by completing the Google Form through the following link:
https://forms.gle/uwEBRdR6HBdM2oG47

Although **this research is ultimately aimed at improving learning for everyone across many disciplines and locations**, the very first step of this substantial project is being conducted amongst UCC students. I would be delighted if you could volunteer and really appreciate your time.

If you have any further questions, feel free to contact me directly by email at: scioptle@gmail.com.

Enquiries can also be sent to Prof. Tommie McCarthy by email to: t.mccarthy@ucc.ie or by phone to: (021) 420 5436

Yours sincerely,

Anna Scanlan
PhD Researcher: Schools of Biochemistry and Cell Biology, and School of Education, University College Cork

Figure A.2

Sample Email Outlining the Bonus for KLS Study Volunteers

MENTORSHIP AND COACHING TALK FOR SCIOPTLE VOLUNTEERS.

A new approach to your CV

Flipping you Curriculum Vitae into your Vitae Curriculum

Mapping the Road Forward for Your CV

Friday May 22nd from 12-1pm on Microsoft Teams

As first years, you have many options for going forward with your CV development

BUT how do you know which option is best for you?

HOW do you know the best road to take?

In this session, I will share with you the key advice that has proven to be successful for numerous science students going forward and given that we are in covid-19 times, I will also share some ideas for having a productive, rewarding and CV building summer.

DONT FORGET

WE ARE RUNNING THE FIRST SCIOPTLE TEST NEXT MONDAY AND HOPE THAT YOU CAN PARTICIPATE

We have now adapted our study to run fully online and are planning to test our first online learning technique next Monday, May 18th from 11am to 12.10pm (70 mins total including MCQ). In this test, you will be presented with a second-year science topic from ML2001 (which all of you will take next year), engage with it for a short time and then answer a short set of MCQs. We will then analyse the MCQ performance to determine the effectiveness of the learning technique. We will return your test scores to you once analysed.

Please email scioptle@gmail.com if you are available on Monday next to participate in the test and Anna will forward details.

Best Regards,

Tommie

Figure A.3

Sample Email with Instructions for Participating in Experiment 3

Dear Student,

Thank you for signing up to our Scioptle study which aims to make learning easier, faster, more enjoyable and with improved long-term recall.

In advance of the study, please double-check that you have Microsoft PowerPoint installed on your computer. All students in UCC have free access to Microsoft Office apps, including PowerPoint. More information on how to install Microsoft Office for free can be found at:

https://www.ucc.ie/en/sit/support/faq//0365/

All students participating are being assigned a 4-digit numeric code to ensure their anonymity is maintained throughout the study. The code you receive is unique to you and should be kept confidential. Your anonymous code is: **xxxx** (not real code)
Please keep it close to hand on the day of your test.

On the day of the study (Mon 1st Nov):

- An email will be sent to your student account from scioptle@gmail.com at 1:50 pm
- That email will have a PowerPoint attached. Depending on the group you have been randomly assigned to, the PowerPoint will be labelled as either:
  Lac Oranges, Lac Grapes, or Lac Kiwis
- Download the PowerPoint fully and feel free to read through the instructions before the study session begins at 2 pm.
- If you have difficulty downloading files (e.g., if using an iPad), the PowerPoint can instead be saved to 'files' and then opened.
- **At precisely 2 pm,** you can proceed through the lesson slides in the PowerPoint. It is important to the integrity of the study that all participants begin at the same time for a fair group comparison. *Individual results will not be compared*.
- Once the PowerPoint is open, click on 'Enable Editing.' This will allow you to interact with icons on screen if you are in one of the interactive groups.
- To check that all the above steps work smoothly for you (download speeds etc.), **a practice PowerPoint file will be sent in an email from Scioptle@gmail.com** for you to download. You can discard this PowerPoint once you have opened it.

Should you encounter any difficulties with any of the steps, you can contact me by email to: scioptle@gmail.com using the subject line: Troubleshooting KLS.
Enquiries can also be sent to Prof. Tommie McCarthy by email to: t.mccarthy@ucc.ie or by phone to: (021) 420 5436

All the best,
Anna Scanlan
PhD Researcher: Schools of Biochemistry and Cell Biology, and School of Education, University College Cork

Figure A.4

Thank You Email with Request for Feedback

Dear Scioptle Volunteer,

Thank you so much for setting your time aside to be a part of our Scioptle Research Project. You completed an advanced science lesson that is normally taught at 2nd and 3rd year undergraduate level, after many months of introduction to the foundational language and concepts of science - well done!

This project will be significant in designing a suite of techniques to apply when learning material online, beginning with complex science topics which are often abstract and difficult to conceptualise. Our intention is to develop a framework that will extend to other education disciplines. Please feel free to forward any feedback you might have on your experience today e.g.:

1. Were the instructions on how to proceed clear and unambiguous?
2. Was it an enjoyable experience?
3. Do you feel this approach towards learning is stressful / less stressful?
4. Did you encounter any technical difficulties during the study?
5. Did you use a trackpad, mouse or touch screen?
6. Do you have any suggestions to improve the learning experience?

You are amongst some of the earliest participants to take part in this project - again, thank you.

All the best,
Anna Scanlan
Prof. Tommie McCarthy

Figure A.4

Sample Online Participant Information, Consent Form and Questionnaire

Section 1 of 4

Scioptle Research Participant Information, Consent Form and Questionnaire

Thank you for your interest in this SCIOPTLE research project. Section 1 of this document provides information that enables you to make an informed choice about participating in this study. Section 2 is the Consent Form which requires your agreement to participate. Section 3 contains a short questionnaire for completion after you sign the consent form. Once you have completed the form, click 'submit' at the end.

Please provide your STUDENT EMAIL ADDRESS below (this will be replaced with an anonymous code):

EMAIL*

Valid email

After section 1

Continue to next section

Section 2 of 4

Section 1. PARTICIPANT INFORMATION

Research Project Title: Development and Evaluation of Online Approaches for Improved Kinaesthetic Learning in Science

Investigators: Prof. Tommie McCarthy, School of Biochemistry, UCC; Dr. Declan Kennedy, School of Education, UCC; Anna Scanlan, PhD candidate (Biochemistry and Education, UCC);

Contact details
Prof. Tommie McCarthy, Email: t.mcccarthy@ucc.ie
Anna Scanlan, Email: scioptle@gmail.com

The purpose of this study is to develop approaches and tools to enhance learning with a specific focus on kinaesthetic learning (learning by doing). We have developed new on-screen kinaesthetic approaches that we believe will help users to improve their learning. The aim of this study is to evaluate the effectiveness of these approaches and tools using volunteer students. This study is restricted to students over the age of 18.

Should you choose to participate, you will be asked to:

a) complete a consent form
b) complete a short questionnaire
And at a later point, you will be asked to participate in a 1hr session where you will a) engage with a short online science lesson, b) use a specific study approach to learn the lesson, c) complete a short multiple choice question (MCQ) assessment to measure the

effectiveness of the learning technique and d) complete a second 15 minute MCQ/SAQ assessment approximately 1 week later to measure long-term learning.

Participation in this study is completely voluntary. There is no obligation to participate and should you choose to do so you can refuse to answer specific questions or decide to withdraw from the study at any time during or after the study. All information you provide will be confidential and your anonymity will be protected throughout the study in accordance with research ethics guidelines and best practice. It will be necessary to gather identifying information with the questionnaire so that we can link your details to your test. We will replace your name with a code on your questionnaire and on your test. The details linking your code to your name will be stored separately from details of your questionnaire and test responses to ensure confidentiality.

The anonymous questionnaire and test data will be stored securely on the University College Cork OneDrive system and subsequently on the UCC server as per UCC directions for secure storage of confidential data. The information linking codes to participant names will be stored separately on a secure UCC drive in a password protected format. We are obliged to store the data for a minimum of ten years. After this point the data will be deleted. The test results you provide may contribute to group result findings which may be published in research publications and/or conference presentations and/or MSc / PhD theses.

We do not anticipate any negative personal outcomes from participating in this study. This study has obtained ethical approval from the UCC Social Research Ethics Committee.

If you have any queries about this research, you can contact Prof. Tommie McCarthy by email at t.mcccarthy@ucc.ie

If you agree to take part in this study, please complete the consent form.

Yours sincerely,

Prof. Tommie McCarthy and Anna Scanlan

Continue to next section

Section 3 of 4

Section 2. CONSENT FORM

This study is restricted to students over the age of 18.

CONSENT CLAUSES

1. I am over 18 years of age.
2. I am volunteering to participate in the research study, the "Development and evaluation of online approaches for improved kinaesthetic learning in science."
3. The purpose and nature of the study has been explained to me in writing.
5. I understand that I can withdraw from the study without repercussions at any time before it starts, while I am participating, or within 2 weeks of completion.
6. I understand that anonymity of my personal data will be ensured and that my identity will be kept confidential.

Insert your name here:

*

Short answer text

I confirm that I understand the consent clauses 1 to 6 above and I consent to participate in this study
*

- YES
- No

After section 3
Continue to next section

Section 4 of 4

Section 3. Questionnaire for Participants

This questionnaire asks for some additional information relating to your study habits and preferences to inform our research.

1. Year of Birth

Short answer text

2. Gender

Short answer text

3. Have you previously completed a module or course in the biological science area (e.g., biochemistry, biotechnology, genetics, microbiology, neuroscience, physiology, plant science, zoology) at third level / post leaving certificate level?

- Yes
- No

4. Title of College Course in which you are enrolled

Short answer text

5. Is English your first language?

- Yes
- No

6. Are you registered with a disability service for learning purposes (as distinct from physical or mental health purposes)?

- Yes
- No

7. How often do you use a computer, laptop or tablet device for engaging with lecture material on your course during term time, outside of lectures?

- Very often - t
- Frequently -

Infrequently -
Rarely - less

8. How often do you use a smart phone for engaging with lecture material on your course?

Very often - t
Frequently -
Infrequently -
Rarely - less

9. Approximately how many hours do you spend studying weekly during term time (excluding attendance at lectures, labs and completing specific assignments)?

2-5 hours
6-10 hours
11-15 hours
16-20 hours
0ver 20 hour

10. In order to study something new from a lecture, I read lecture notes repeatedly

Very Rarely ○ ○ ○ ○ ○ Very Often

11. For study I write out my own notes from lecture notes

Very Rarely ○ ○ ○ ○ ○ Very Often

12. For study I listen to lecture recordings

Very Rarely ○ ○ ○ ○ ○ Very Often

13. For learning I study the diagrams and drawings provided

Very Rarely ○ ○ ○ ○ ○ Very Often

14. For study I use mind maps

Very Rarely ○ ○ ○ ○ ○ Very Often

15. Rank-order the top 5 learning strategies that you use below assigning 1 for the strategy used most often etc. If you use strategies not shown here, please proceed to the next question.

Rank 1 | Rank 2 | Rank 3 | Rank 4 | Rank 5

Rereading notes or textbook

Rewriting notes

Practicing questions WITH help of notes and text

Practicing questions WITHOUT help of notes and text
Make outlines or review sheets
Using flashcards
Highlighting Notes / Text
Using mnemonics (acronyms, rhymes, etc)
Memorising text
Studying with a group of students
Listening to recorded material

16. If your study strategy is not catered for above, rank-order your top 5 study strategies assigning the top rank to the strategy used most often, e.g., rank 1 - rereading, rank 2 - rewriting notes etc.

Long answer text

17. Are you easily distracted during study

Rarely distracted ○ ○ ○ ○ ○ Very easily distracted

18. Are you colour blind?

- Yes
- No

19. Are you left or right-handed?

- Left
- Right
- Ambidextrou

20. For the research study, I plan to use a:

- Desktop cor
- Laptop
- Tablet

21. To interact with content on the screen of my device, I will use a:

- Tracker pad
- Mouse
- Touchscreer

After completing the forms, please click on submit. THANK YOU FOR VOLUNTEERING - your participation in our research

Appendix B

This section includes a schematic of the thematic analysis from experiment 2 and a sample of two quizzes at different stages of the study, i.e., the MCQ from experiment 2 and the MSQ for the second timepoint test of experiment 5.

Figure B.1

Sample Lac Operon MCQ

Scioptle
Science Optimised in Learning

Exploring the Development and Evaluation of Online Approaches for Improved Kinaesthetic Learning in Science

Investigators, Prof. Tommie McCarthy, Dr. Declan Kennedy and Anna Scanlan
School of Biochemistry and Cell Biology and School of Education, University College Cork.
Contact details for Prof. Tommie McCarthy, email t.mcccarthy@ucc.ie; phone (021 4205436)

Please enter your four-digit random identification number here _____

Please circle <u>one</u> correct answer in each question

1. Choose the correct order in which the Lac proteins are produced.

a) Beta-galactosidase, trans-acetylase, permease
b) Beta-galactosidase, permease, trans-acetylase
c) Permease, beta-galactosidase, trans-acetylase
d) Trans-acetylase, permease, beta-galactosidase
e) Trans-acetylase, beta-galactosidase, permease

2. The production of protein follows a specific sequence of events. Below is a list of events for you to consider:

A. RNA polymerase transcribes genes
B. RNA polymerase translates genes
C. The top strand of DNA is used as a template to make mRNA
D. The bottom strand of DNA is used as a template to make mRNA
E. Ribosomes translate mRNA into protein
F. Ribosomes transcribe mRNA into protein

Choose the correct sequence of events from below:

a) A, D and E are correct
b) B, C and F are correct
c) A, C and E are correct
d) B, D and F are correct
e) A, C and F are correct

Which scenario indicates that the Lac Operon is being repressed?

a) RNA polymerase is transcribing the Lac genes
b) The Lac proteins are being produced
c) RNA polymerase is bound to the Lac operon, but the genes are not being transcribed
d) The cAMP molecule is bound to CAP forming the CAP-cAMP complex
e) Allolactose has altered the structure of the Lac repressor

4. Determine the correct order of the regulatory sites in the Lac operon.

a) Cap Binding Site - Promoter - Operator
b) Promoter-Operator-Cap Binding Site
c) Operator -Promoter-Cap Binding Site
d) Promoter-Cap Binding Site-Operator
e) Operator-Cap Binding Site-Promoter

5. What does the enzyme encoded by the Lac A gene do?

a) Splits lactose into glucose and galactose
b) Converts lactose into allolactose
c) Transcribes DNA into RNA
d) Adds a small acetyl group to lactose
e) Activates the lac promoter

6. In the Lac Operon, certain proteins bind specifically to regulatory sites on DNA. Which one of the following options is correct?

a) RNA polymerase binds to the Lac operator
b) CAP-cAMP complex binds to the Lac promoter
c) Lac repressor binds to the Lac promoter
d) RNA polymerase binds to the CAP binding site
e) Lac Repressor binds to the Lac operator

7. What molecule does the Lac Operon depend on to sense the presence of glucose?

a) Lactose
b) Cyclic-adenosine monophosphate (cAMP)
c) Glucose
d) Catabolite activator protein (CAP)
e) Allolactose

8. What is the name of the enzyme that splits lactose apart?

a) Allolactose
b) Permease
c) Beta-galactosidase
d) Trans-acetylase
e) RNA polymerase

9. Assume the Lac Operon is being actively transcribed in *E. coli* in a culture media. Predict what will happen if glucose is added to the media.

a) *E. coli* will continue to feed on lactose until it is depleted, then return to feeding on glucose
b) The presence of glucose will slow down the growth of *E. coli*
c) The Lac operon will be turned off immediately and *E. coli* will start feeding on glucose
d) *E. coli* will feed on both glucose and lactose together until each is depleted
e) The presence of glucose will maintain transcription of the Lac genes

10. Choose the correct statement:

a) The Lac operon is an example of both positive and negative gene regulation
b) The CAP-cAMP complex grabs RNA polymerase and recruits it to the Lac operator
c) The Lac repressor is a positive regulator of the Lac operon
d) cAMP binds directly to the CAP-binding site on DNA
e) The Lac genes will be transcribed if both glucose and lactose are present



11. Identify the sugar combination that will yield the highest production of Lac mRNA:

a) High glucose, high lactose
b) No lactose, high glucose
c) High glucose, low lactose
d) Low glucose, low lactose
e) No glucose, high lactose

12. What protein is encoded by the Lac Y gene?

a) Allolactose
b) Permease
c) Beta galactosidase
d) Trans-acetylase
e) RNA polymerase

13. Assume that the Lac operator has been deleted from *E. coli*. Predict the outcome for the Lac Operon.

The Lac genes will be:

a) Transcribed when lactose is present, regardless of the presence of glucose
b) Transcribed in the presence of glucose only
c) Repressed permanently, regardless of the presence of lactose
d) Transcribed only when lactose is present and glucose is absent
e) Repressed when in the presence of glucose and presence of lactose

14. What effect does allolactose have on the Lac repressor?

a) It binds to the operator and prevents the Lac repressor from attaching
b) It alters the repressors shape and strengthens its grip on DNA by 1000-fold
c) It binds to the CAP binding site and prevents the Lac repressor from attaching
d) It alters the repressors shape and weakens its grip on DNA by 1000-fold
e) It attaches to the repressor and forms a complex that acts as a positive regulator of the Lac operon

15. What protein is encoded by the Lac Z gene?

a) Trans-acetylase
b) Allolactose
c) Beta-galactosidase
d) RNA polymerase
e) Permease

16. Identify the negative regulator of the Lac operon.

a) Lac repressor
b) Lac promoter
c) CAP-cAMP complex
d) Lac operator
e) Lactose

17. Which one of the following is a positive <u>regulator</u> of transcription?

a) RNA polymerase
b) The CAP-cAMP complex
c) The Lac repressor in its altered shape
d) The Lac repressor in its un-altered shape
e) Glucose



18. What is the function of the enzyme Beta-galactosidase?

a) It splits lactose into glucose and galactose
b) To allow lactose to enter E. coli from the environment
c) It attaches a small acetyl group to lactose
d) It recruits RNA polymerase to the Lac operon
e) It attaches a small acetyl group to CAP

19. Assume that the gene encoding Permease has been deleted from *E. coli.* Predict the outcome for the Lac operon.

a) The entry of lactose into the *E. coli* will be enhanced
b) Lactose can only enter *E. coli* once the Lac genes are transcribed
c) *E. coli* will grow well on a medium containing only lactose
d) Lactose can no longer enter *E. coli* from the external environment
e) *E. coli* will not grow well on a medium containing only glucose

20. You are a scientist who has deleted the CAP-binding site from *E. coli*. Predict the outcome you expect for the Lac operon.

a) There will be strong transcription of the Lac genes in the presence of both lactose and glucose
b) The CAP-cAMP complex will recruit RNA polymerase to bind to DNA and the Lac genes will be transcribed
c) The Lac repressor will remain permanently detached from its binding site leaving the Lac genes free for transcription
d) The Lac genes will be strongly transcribed in the presence of lactose and absence of glucose
e) The CAP-cAMP complex will form but will be unable to bind to DNA and recruit RNA polymerase

21. Assume *E. coli* had a permanent deficiency in cAMP production and could not produce cAMP under any circumstances. How would this affect the E. coli's ability to metabolise lactose?

a) The *E. coli* will not be able to metabolise glucose effectively and will instead metabolise lactose
b) On a media containing both glucose and lactose, the *E. coli* will not be able to compete with or outgrow other bacteria that do not have the cAMP production deficiency
c) High levels of glucose will no longer prevent *E. coli* from metabolising lactose
d) Low levels of glucose will compensate for the lack of cAMP and the *E. coli* will have the ability to metabolise lactose
e) The deficiency will have no effect on *E. coli*'s ability to metabolise lactose

22. An educator purchased an E. coli mutant in which the lac operator DNA sequence had been removed. The educator asked her students to predict the characteristics (phenotype) of this *E. coli*. The students gave the following four answers:

A. RNA polymerase will be able to access and transcribe the Lac genes
B. RNA polymerase will not be able to access nor transcribe the Lac genes
C. Lac mRNA will be produced regardless of the levels of glucose, if lactose levels are high
D. Lac mRNA will be produced if glucose levels are low, regardless of the levels of lactose

Select the correct combination below:

1. **A and B are correct - C and D are incorrect**
2. **B and C are correct - A and D are incorrect**
3. **A and D are correct - B and C are incorrect**
4. **A and C are correct - B and D are incorrect**
5. **D is correct - A, B and C are incorrect**



23. Scientists discovered a gene located near (but separate to) the Lac Operon. They noticed that this gene was being transcribed continuously in the bacterial cell. To discover the function of this gene, scientists deleted it. The scientists then observed that lots of Lac mRNA was being produced on media containing low glucose but no lactose.

Based on this new information, what protein do you think is encoded by the deleted gene?

a. RNA polymerase
b. Beta-galactosidase
c. Lac Repressor
d. CAP
e. Lac Permease

24. X-gal is a synthetic molecule that can be broken down by beta-galactosidase. When it is broken down it generates a blue colour. X-gal has no effect on the Lac operon and can be included in *E. coli* growth media. *E. coli* that break down X-gal appear as blue colonies on an agar plate, whereas *E. coli* that cannot break down X-gal appear white. Scientists treated a population of *E. coli* with a chemical that randomly damaged their genes. The scientists then grew the *E. coli* as individual colonies on agar plates. Each colony stemmed from a single bacterium. They observed that some of the colonies were blue, while other colonies were white. They took a white colony and grew it on media with X-gal and lactose; and on media with X-gal, glucose and lactose. In all cases, the colony remained white. There are several possible reasons for this given below but one of the answers is impossible.

Identify the <u>FALSE</u> answer.

a) The Lac Z gene could be damaged
b) The gene for the Lac repressor could be damaged so the repressor becomes unresponsive to allolactose
c) The gene encoding CAP could be damaged so that CAP stays attached to its binding site in the presence of glucose and/or lactose
d) The Lac promoter could be damaged so RNA polymerase can no longer recognise it
e) The CAP-binding site could be damaged so that the positive regulator can no longer recognise it

25. Scientists were interested in producing human insulin in *E. coli*. They asked students for ideas on how to do this in a way that transcription of the insulin gene (INS), could be visibly observed.

Which one of the following suggestions is likely to succeed?

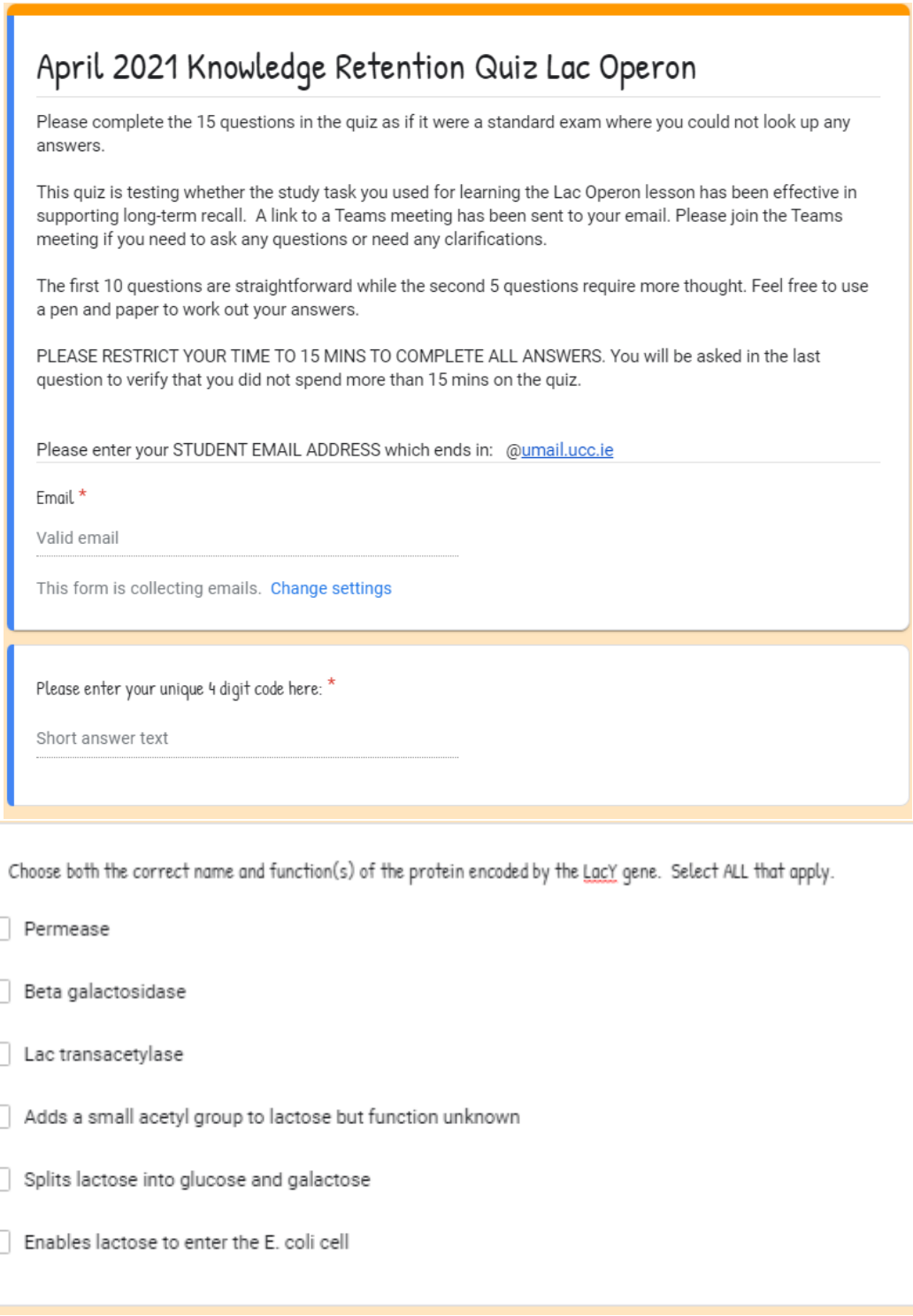
a) Insert the INS gene at the end of the Lac Z gene and grow the *E. coli* in media containing lactose and X-gal
b) Insert the INS gene before the Lac operator and grow in a media containing glucose and X-gal
c) Replace the Lac Z gene with the INS gene and grow in a media with lactose and X-gal
d) Replace the Lac promoter with the INS gene and grow in a media of glucose and X-gal
e) Insert the INS gene at the end of the Lac Z gene and grow the E. coli in media containing glucose and X-gal

Thank you so much for your time - we really appreciate it!



Figure B.2

Experiment 5 Timepoint 2 Quiz



April 2021 Knowledge Retention Quiz Lac Operon

Please complete the 15 questions in the quiz as if it were a standard exam where you could not look up any answers.

This quiz is testing whether the study task you used for learning the Lac Operon lesson has been effective in supporting long-term recall. A link to a Teams meeting has been sent to your email. Please join the Teams meeting if you need to ask any questions or need any clarifications.

The first 10 questions are straightforward while the second 5 questions require more thought. Feel free to use a pen and paper to work out your answers.

PLEASE RESTRICT YOUR TIME TO 15 MINS TO COMPLETE ALL ANSWERS. You will be asked in the last question to verify that you did not spend more than 15 mins on the quiz.

Please enter your STUDENT EMAIL ADDRESS which ends in: @umail.ucc.ie

Email *

Valid email

This form is collecting emails. Change settings

Please enter your unique 4 digit code here: *

Short answer text

1. Choose both the correct name and function(s) of the protein encoded by the LacY gene. Select ALL that apply.

- [ ] Permease
- [ ] Beta galactosidase
- [ ] Lac transacetylase
- [ ] Adds a small acetyl group to lactose but function unknown
- [ ] Splits lactose into glucose and galactose
- [ ] Enables lactose to enter the E. coli cell

2. Choose the correct name and function(s) of the protein encoded by the LacZ gene. Select ALL that apply.

- [ ] Lac transacetylase
- [ ] Beta galactosidase
- [ ] Enables lactose to enter the E. coli cell
- [ ] Permease
- [ ] Can alter the bond between in lactose to form allolactose
- [ ] Splits lactose into glucose and galactose

3. Choose the correct name and function(s) of the protein encoded by the LacA gene. Select ALL that apply.

- [ ] Beta galactosidase
- [ ] Permease
- [ ] Adds a small acetyl group to lactose but function unknown
- [ ] Can alter the bond between lactose to form allolactose
- [ ] Lac transacetylase
- [ ] Enables lactose to enter the E. coli cell

4. What role does the catabolite activator protein (CAP) play in the Lac Operon? Select ALL that apply.

- [ ] In the absence of glucose, CAP is activated by cAMP to form the CAP-cAMP complex
- [ ] The CAP-cAMP complex is the positive regulator of the Lac Operon
- [ ] CAP is the positive regulator of the Lac Operon
- [ ] CAP recruits RNA polymerase to bind to the Lac promoter
- [ ] In the presence of glucose, the CAP-cAMP complex is the negative regulator of the Lac Operon

5. What role does the Lac repressor play in the Lac Operon? Select ALL that apply.

- [ ] The Lac repressor sits on the Lac promoter located immediately before the Lac genes
- [ ] The Lac repressor sits on the Lac operator located immediately before the Lac genes
- [ ] The Lac repressor recruits RNA polymerase to bind to the promoter
- [ ] The Lac repressor physically blocks RNA polymerase from transcribing the Lac genes
- [ ] The Lac repressor is both the positive and negative regulator of the Lac operon
- [ ] The Lac repressor is the negative regulator of the Lac operon

6. What is the difference between the active state vs. inactive state of the key protein responsible for positive regulation of the Lac Operon? Select ALL that apply.

- [ ] Active: CAP-cAMP complex recruits RNA polymerase to the Lac promoter = Lac genes transcribed
- [ ] Active: Lac repressor recruits RNA polymerase to the Lac operator = Lac genes transcribed
- [ ] Active: CAP recruits RNA polymerase to the Lac promoter = Lac genes transcribed
- [ ] Inactive: Lac repressor remains on the Lac promoter = no Lac gene transcription
- [ ] Inactive: CAP does not recruit RNA polymerase to the Lac promoter = Lac genes transcribed
- [ ] Inactive: CAP-cAMP complex does not form, RNA polymerase is not recruited = no Lac gene transcription

7. What is the difference between the active state vs. inactive state of the key protein responsible for negative regulation of the Lac Operon? Select ALL that apply.

- [ ] Active: CAP recruits RNA polymerase to the Lac promoter = Lac genes transcribed
- [ ] Active: CAP-cAMP complex recruits RNA polymerase to the Lac promoter = Lac genes transcribed
- [ ] Active: Lac repressor remains on the Lac operator blocking RNA polymerase = no Lac gene transcription
- [ ] Inactive: CAP-cAMP complex does not form, RNA polymerase is not recruited = no Lac gene transcription
- [ ] Inactive: Lac repressor falls off the Lac operator = Lac genes exposed for transcription by RNA polymerase
- [ ] Inactive: CAP does not recruit RNA polymerase to the Lac promoter = Lac genes transcribed

8. Which one of the following correctly identifies the structure of the three elements present in DNA located before the three genes of the Lac Operon?

- CAP binding site, Lac promoter, Lac operator
- CAP-cAMP complex, Lac promoter, Lac repressor
- Lac promoter, CAP binding site, Lac operator
- CAP binding site, Lac operator, Lac promoter
- CAP, Lac promoter, Lac repressor

9. Which one of the following correctly describes the order and function of each of these elements?

- Lac promoter is site for RNA polymerase, Lac repressor is site for Lac operator, CAP is site for cAMP
- CAP binding site is site for cAMP; Lac promoter is site for Lac repressor; Lac operator is site for RNA pol...
- CAP binding site is site for CAP-cAMP complex; Lac promoter is site for RNA polymerase and Lac operat...
- CAP binding site is site for CAP; Lac operator is site for Lac repressor; Lac promoter is site for RNA poly...
- Lac promoter is site for Lac repressor, CAP binding site is for CAP-cAMP complex, Lac operator is for RN...

10. Assume you created a mutant E. coli where you deleted the gene for the CAP molecule from the E. coli genome. Predict the effect that this deletion would have on transcription of the Lac genes in E. coli grown on a media where glucose is absent and lactose is present?

- E. coli will be able to feed on lactose instead
- There will be positive regulation through recruitment of RNA polymerase = Lac genes will be transcribed
- cAMP will bind to RNA polymerase and the Lac Z-Y-A genes will be strongly transcribed
- The absence of the CAP gene means there will be no negative regulation of the Lac Operon
- There will be no recruitment of RNA polymerase and no positive regulation = Lac genes will not be transc...

11. Assume you created a mutant E. coli where you deleted the Lac operator from the E. coli genome. Predict the effect that this deletion would have on transcription of the Lac genes when the E. coli mutant is grown on a media in which glucose and lactose are absent?

- ○ As glucose is absent, the CAP-cAMP complex will not form and RNA polymerase will not be recruited
- ○ RNA polymerase will be recruited but will not be able to bind effectively to the DNA = no transcription
- ○ Transcription will proceed as the Lac repressor has no site from which to block RNA polymerase
- ○ The Lac repressor will be bound permanently to DNA and Lac genes will never be exposed
- ○ E. coli will thrive on the media in the absence of the Lac operator

12. Assume you created a mutant E. coli where you deleted the Lac Z gene from the E. coli genome. Predict the effect that this deletion would have on transcription of the Lac genes in E. coli grown on a media in which glucose is absent and lactose is present?

- ○ No effect as the Lac Y and Lac A genes will still be transcribed
- ○ Lactose will be able to enter the cell but cannot be utilised
- ○ In the presence of allolactose, the repressor will fall off the DNA and the Lac genes will be transcribed
- ○ In the absence of allolactose, the repressor remains on DNA and prevents Lac gene transcription
- ○ Lactose will be broken down and utilised but allolactose will not form

13. Assume you created a mutant E. coli where you deleted the Lac Y gene from the E. coli genome. Predict the effect that this deletion would have on E. coli grown on a media in which glucose is absent and lactose is present?

- ○ The entry of lactose into the E. coli will be enhanced = E. coli will thrive
- ○ Lactose can no longer enter E. coli from the external environment = E. coli will die
- ○ No effect as the Lac Z and A genes will still be transcribed
- ○ E. coli will survive but there will be low transcription of the Lac genes
- ○ The Lac repressor will remain permanently detached from DNA

14. Assume that you genetically manipulated E. coli so that you created an E. coli where you inserted the human insulin gene into the Lac Operon in place of the lac A gene. Predict what would happen if this E. coli was grown on a medium containing lactose but no glucose.

- ○ The Lac Z, Y and insulin genes will be transcribed, insulin be produced and will break down glucose for E....
- ○ The Lac Z and Y genes will be produced but the insulin gene will not be transcribed
- ○ The Lac Operon will be able to use insulin when glucose and lactose are absent
- ○ The Lac Z, Y and insulin genes will be transcribed, insulin will be produced but will play no role in the Lac ...
- ○ Inserting the insulin gene will kill the E. coli

15. Assume that you genetically manipulated an E. coli so that you changed the order of the three elements in the DNA in front of the genes of the Lac Operon so that the Lac Operator was the first element. Predict what would happen if this E. coli was grown on a medium in which glucose and lactose were absent?

- ○ The Lac genes will be exposed but RNA polymerase will not be recruited = no transcription
- ○ The repressor will bind to DNA and prevent transcription of the Lac genes
- ○ The repressor will not be able to prevent RNA polymerase from transcribing the Lac genes
- ○ The CAP-cAMP complex and RNA polymerase will no longer be able to attach to the Lac Operon
- ○ Lac genes will not be transcribed and without the lactose substrate, E. coli will die

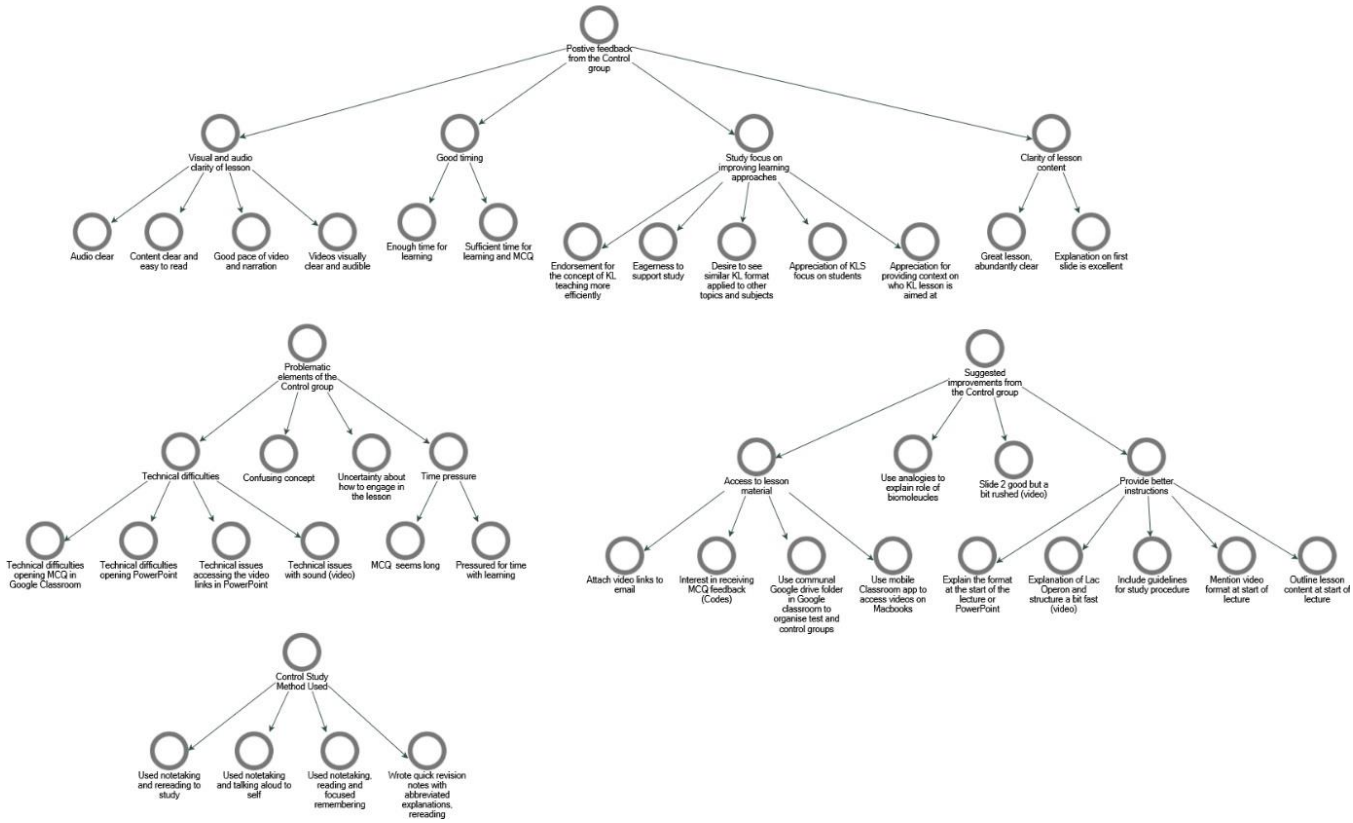
Quiz time confirmation *

- ☐ I confirm that I spent no longer than 15 minutes on this quiz

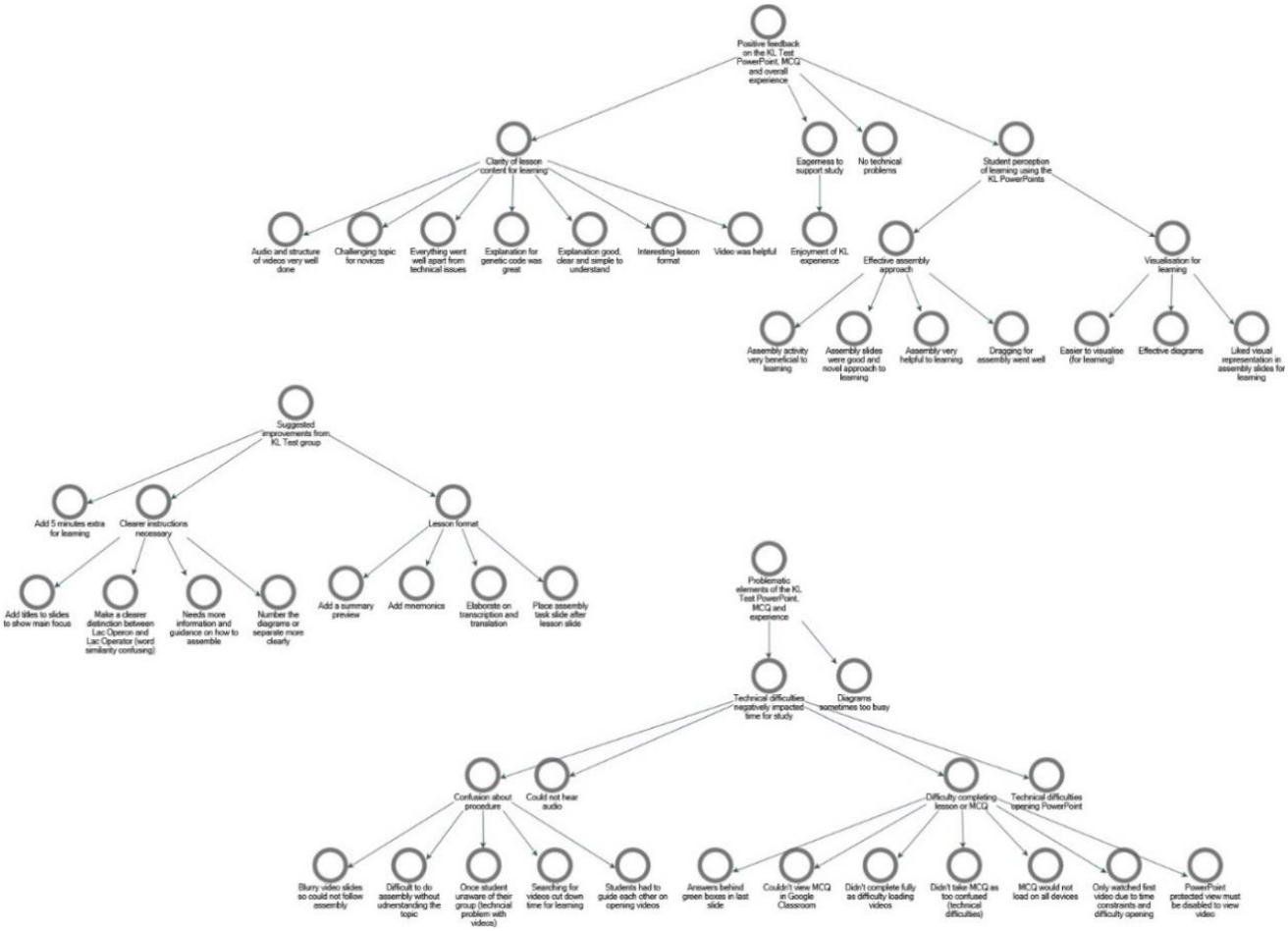
Figure B.3

Experiment 2 Thematic Framework

B.3.i. Control Group Feedback



B.3.ii. Lac Test Interaction Group Feedback



Note. Schematic of the thematic framework arising from the feedback of (C.2.i.) the Control group and (C.2.ii.) the Lac Test Interaction group.

Appendix C

This section contains communication, lesson material and SPSS tables for the secondary school study, Experiment 7.

Figure C.1

Instructional Email to Secondary Schools who Agreed to Participate

Dear Teacher,

Thank you for the interest you expressed in facilitating the Scioptle PhD Research Project for Secondary Schools prior to the Christmas break. I appreciate that many schools have been impacted by student and staff shortages since their return leading to difficulties in running normal classes. However, I am hopeful that the online nature of this UCC study will enable teachers to continue with the plan to facilitate this research within the next week or two whether from a classroom computer, or from a home laptop.

The study timing is suitable to run as a single class but a double class will allow for any unforeseen technical issues to be resolved. The initial advice was to have teachers play a video lesson on DNA transcription and translation within the classroom. However, should the teacher or any student be working from home, it would be possible instead to play the video live online to the class.

A YouTube link for the video is: https://youtu.be/-aASt927MYY

It was brought to my attention that some schools do not have access to YouTube; therefore, please find attached an MP4 version of the video which does not contain links to any external websites and is a suitable alternative. Simply download the MP4 and play it by sharing your screen with the students, or by providing them with the MP4 on the day of testing.

A reminder of the timing for running the study is as follows:

- (8 min) Play a video lesson on DNA transcription and translation – teacher plays this to the class
- (25 min) PowerPoint lesson and study task completion – students complete independently on laptops/chrome books/desktop computers.
- (10 min) Google Form Quiz – results are returned automatically to researchers when student's click 'submit'. No further study of the lesson prior to Quiz 2
- Seven days later (10 min) Google Form Quiz 2 – results returned automatically as previous

In facilitating this study, **you do not need to have any knowledge of science as you will not be required to teach the topic or to grade it**. The '*DNA Research Lesson'* is set-up for self-directed learning by the student in PowerPoint. The student cohort we would like to use are those in Transition Year and/or Senior Cycle classes. **Students do not have to be taking science** although it will undoubtably benefit those who are.

You will have received a self-contained 'School Lesson Pack' with all the necessary documents to facilitate the study. Please could you ensure that any student who wishes to participate provides parental consent (if under 18) using the UCC forms provided in the Lesson Pack, or by using your

school's preferred method of gathering consent. I will arrange to collect the record of consent from each school shortly after completion of the study.

Please note that all students who volunteer must be issued with an anonymous code from the Excel sheet provided in the Lesson Pack to protect their anonymity in Quiz 1 and 2, as well as to maintain the anonymity of the school.

Some teachers who have small class sizes queried whether they could participate, and the answer is absolutely. Simply divide the class as evenly as possible to the conditions assigned to you in the Lesson pack and all school results will be subsumed into each condition. I will be holding a short Zoom meeting this Wednesday at 1:15 pm for 15 mins for any teacher who would like clarification on any aspect of the study. Please see the following details to participate:

Anna Scanlan is inviting you to a scheduled Zoom meeting.

Figure C.2

Secondary School Pack Containing the Invitation, Information, Consent and Assent Forms for Participation in the KLS Study



Coláiste na hOllscoile Corcaigh, Éire
University College Cork, Ireland

School of Biochemistry & Cell Biology
Western Gateway Building
University College Cork
Cork

Invitation of participate in testing of "learning by doing" approaches for learning and understanding science

Investigators, Prof. Tommie McCarthy*, Dr. Declan Kennedy** and Anna Scanlan*
*School of Biochemistry and Cell Biology and **School of Education, University College Cork.
Contact details for Prof. Tommie McCarthy - email t.mcccarthy@ucc.ie; - mobile (086 xxxxxxxx)

Participant Information Sheet

This aim of our research is to try and make difficult science topics easier to understand and learn for secondary school students. The most common approach for learning in science uses text and diagrams. Another approach is "learning by doing". This approach is called kinaesthetic learning. While laboratory work in science has lots of kinaesthetic learning, the theory aspects do not. We think that adding kinaesthetic learning approaches to the theory aspects will make science easier to learn and understand. We want to test this idea and invite you to help us with these tests.

We have developed new kinaesthetic approaches and tools that can be used on your computer with science lessons. The aim of this research study is to test these approaches and tools using secondary school student volunteers to see how well they work for helping you learn.

If you choose to participate,

a) you will be asked to sign an assent form agreeing to participate in the study and your parent or guardian will be asked to sign a consent form on your behalf - if you are over 18, you will be able to sign the consent form only.
b) you will be assigned a code to use instead of your name so that your participation will be anonymous.
c) you will be asked to take part in a short science lesson and to complete a short quiz during a class at school – you will be asked to complete another 15 min follow up quiz about 1 week later.

d) in the class you will be asked to watch a short video on a science topic. This will take about 10-minutes, you will then be asked to study a set of notes on the topic and complete a number of "learning by doing" tasks that are included in the notes. This will take about 15-20 minutes.
e) after you study and complete the set of notes and tasks, you will then be asked to take a short quiz on the topic. This will take about 10-15 minutes.
f) at the start of this quiz, you will be asked a few general questions. These will include a question asking you a) if you could see, read and hear the lesson content, b) your gender c) if English is your first language, d) if you are exempt from any subjects and e) if you used a mouse, touchpad or touchscreen on your computer for the completing the tasks.
g) you will be asked to complete a second quiz on the topic approximately one week later and will be asked not to study the topic in between the two quizzes. The second test allows us to see how much you remembered from the lesson you studied a week earlier.
h) Your quiz results will be anonymous and as such they cannot impact or be used for your school grades.

For participation, your class teacher will assign you to a group. There may be 2-3 groups in the class. Each group will be given the same lesson but different kinaesthetic learning approaches. The results of the quizzes sent to us from each group will be compared and this will allow us to determine which of the kinaesthetic learning approaches used was most effective.

Participation in this study is completely voluntary. There is no obligation to participate, and should you choose to do so you can decide to withdraw from the study at any time during or after the study. All information you provide will be collected anonymously and you will not be asked to provide any identifying information. The anonymous questionnaire and test data that you submit will be stored securely at University College Cork. We are obliged to store the data for a minimum of ten years. After this point the data will be deleted. The anonymous test results you provide may contribute to group result findings which may be published in research publications and/or conference presentations and/or MSc / PhD theses. We do not anticipate any negative outcomes from participating in this study.

This study has obtained ethical approval from the UCC Social Research Ethics Committee.
If you have any queries about this research, you can contact me (Prof. Tommie McCarthy) by email at t.mcccarthy@ucc.ie or by mobile at (086 xxxxxxxx)**.**
If you agree to take part in this study, please complete the assent consent form below and have one of your parents or legal guardians complete the parent / guardian consent form.

University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

Assent Form

I……. [name in CAPS] agree to take part in the research study.

I understand what the study is about, and it has been clearly explained to me.

I am participating voluntarily.

It's fine if I drop out of the study, and I do not have to give any reasons for this.

I understand that the information collected are for research and teaching purposes only for the Scioptle Research Project. I have the right to ask that my data be deleted and not used.

- I can withdraw permission to use the data from the study at any time up until six weeks after the retention quiz is completed, in which case the material will be deleted.

- I understand that with anonymised quizzes it will not be possible to delete my data once submitted to the researchers as the quiz results will not be identifiable to individual students.

I understand that nobody will know it's me in the results or report because my name or any other identifying information will not be linked to my MCQ answers. I understand that my parent(s) / legal guardian(s) must also consent before I can take part in the study.

Name: _____ Date: _____
Signature: _____

☐ **Yes, I consent** to take part in this study.

☐ **No, I do not** consent to take part in this study.

Thank you

University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

Parent / Guardian Consent Form

I…… give permission for my child(ren) to participate in the Scioptle Research Project.

The purpose and nature of the study has been explained to me in writing.
I understand that my child will be participating voluntarily.

I understand that anonymity will be ensured, because personal data is collected only to record consent and is stored separately to data collected from children, with no attempt made to link them. My child's data will have an anonymous identifier made up of letters and numbers.

I understand that my child can withdraw from the study, without repercussions, whether before it starts or while they are participating, and we do not have to give any reasons for this.

I understand that the data and any personal details collected are for research and teaching purposes only within the scope of the Scioptle Research Project. My personal details will be processed and handled in accordance with European legislation including the General Data Protection Regulation (EU) 2016/679. I have the right to access these data, rectify them, limit or oppose their processing and to request deletion of my personal data.

I understand that my child can withdraw permission to use the data at any time up until six weeks after completion of the final retention quiz, in which case the material will be deleted. I understand that after this point, it will not be possible for my child's results to be withdrawn as their data will be fully anonymised. I understand that after ten years all data associated with the study will be destroyed.

I understand that my child's quiz results will remain anonymous in presentations and subsequent publications (journal article, book chapter, student thesis, newspaper article, social media publicity about the study's findings, etc.), if I give permission below (please tick):

I confirm that I am a legal decision-maker for the child(ren) listed below) ☐
I confirm that I have received, read, and understood the information sheet for this study ☐
I consent to my child(ren) participating in this study ☐
I do not consent to my child(ren) participating in this study ☐

Signature: _____ Date: _____

Name (CAPS): _____

Child 1's name (CAPS): _____

Child 2's name (CAPS): _____

Thank you

University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

Consent Form
Please use this form if you are over 18
(no other form required for over 18s)

I……. [name in CAPS] agree to take part in the research study.

I understand what the study is about, and it has been clearly explained to me.

I am participating voluntarily.

It's fine if I drop out of the study, and I do not have to give any reasons for this.

I understand that the information collected are for research and teaching purposes only for the Scioptle Research Project. I have the right to ask that my data be deleted and not used.

- I can withdraw permission to use the data from the study at any time up until six weeks after the retention quiz is completed, in which case the material will be deleted.
- I understand that with anonymised quizzes it will not be possible to delete my data once submitted to the researchers as the quiz results will not be identifiable to individual students.

I understand that nobody will know it's me in the results or report because my name or any other identifying information will not be linked to my MCQ answers. I understand that my parent(s) / legal guardian(s) must also consent before I can take part in the study.

Name: _____ Date: _____

Signature: _____

☐ **Yes, I consent** to take part in this study.

☐ **No, I do not** consent to take part in this study.

Thank you

Figure C.3

Link to Secondary School MCQ



MCQ assessment

You will now have 10 minutes to complete the multiple-choice question (MCQ) quiz

When you open the MCQ, you will see a space to type in the fruit group from this PowerPoint and the unique study code your teacher assigned to you. This will help us to identify which study condition you were in without knowing your name or school

Quiz link:

https://forms.gle/rJFVUCvg7y2FShwE6

Figure C.4

Thank You Email to Secondary School Teachers who Facilitated the Study

Dear (teacher)

Many thanks for running the DNA research lesson with your students – I hope they found the study tasks helpful and the lesson interesting! All quiz results returned will be subsumed into the overall results from other schools to provide a strong overview of which study tasks work best and I look forward to updating you on the final outcome once all data is submitted.

I'm now providing you with the link for Quiz 2 which will take just 10 minutes for students to complete and ideally, is given to students 7 days after Quiz 1.

The link to access Quiz 2 directly is: https://forms.gle/zvQhmH9CGfjjmu9b6

Thank you once again,

Anna Scanlan (087) xxxxxxxx
School of Biochemistry/Education

Appendix D

This section contains communication and a sample final slide containing a link for an MCQ for the postgraduate study, Experiment 8.

Figure D.1

Email to postgrad students on acceptance of the study invitation

Dear Postgraduate Student,

Thank you for signing up to our Scioptle study testing online approaches to improve how complex science topics are learned. The PowerPoint attached has an advanced science lesson of less than 300 words. You do not need prior science to test this lesson.

There is no background information for this topic – you are being thrown in at the deep end to test the effectiveness of the study task assigned to you.

Please download the PowerPoint fully and spend **no longer than 15 minutes** studying the lesson and completing the task. The last slide of the PowerPoint contains a link to a 10-minute Google Form, 'Quiz 1,' which should be completed immediately after studying the lesson.
Please **do not** refer to the PowerPoint while completing the quiz as we wish measure how effective the assigned task was in aiding your recall and understanding of the topic.

Don't worry if you can't remember every detail of the lesson or if you feel you did not understand the topic fully. It is more important that you remain within the set time-limits. We will send you a link in a week's time for another follow-up MCQ, '**Quiz 2'**. This 10-minute quiz will measure the persistence of long-term learning. Therefore, please do not study the lesson again once you have completed the initial study session.

We hope these techniques will be applicable to many disciplines and really appreciate your time and effort in testing them for the benefit of all students.

Many thanks,

Anna Scanlan
School of Biochemistry/Education

Figure D.2

Science Taster Lesson Slides for Experiment 8



You were randomly assigned to the ORANGES group!

Quiz link: https://forms.gle/1gjkxUJLCGdvFofy9

A very **BIG** thank you for volunteering – we really appreciate your participation!

Note. Each study condition was assigned the same fruit for identification as in Experiment 7, i.e., Unguided Assembly were assigned to oranges, Guided Assembly to apples etc. Just one fruit slide is shown here.

Appendix E

This section contains SPSS output tables from the two-timepoint experiments.

Table E.1

Experiment 4 SPSS Output Tables

E.1.i. Timepoint 1 data analysis

Descriptives

Grade

	N	Mean	Std. Dev.	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Min	Max
Unguided Assembly	27.00	76.85	17.11	3.29	70.09	83.62	35.00	100.00
Guided Assembly	28.00	79.64	16.04	3.03	73.42	85.86	40.00	100.00
Question Guided Recall	25.00	87.00	12.50	2.50	81.84	92.16	50.00	100.00
Total	80.00	81.00	15.80	1.77	77.48	84.52	35.00	100.00

ANOVA
Grade

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1416.16	2.00	708.08	2.98	.06
Within Groups	18303.84	77.00	237.71		
Total	19720.00	79.00			

ANOVA Effect Sizes[a,b]

		Point Estimate	95% Confidence Interval Lower	95% Confidence Interval Upper
Grade	Eta-squared	.07	.00	.19
	Epsilon-squared	.05	-.03	.16
	Omega-squared Fixed-effect	.05	-.03	.16
	Omega-squared Random-effect	.02	-.01	.09

a. Eta-squared and Epsilon-squared are estimated based on the fixed-effect model.
b. Negative but less biased estimates are retained, not rounded to zero.

Post Hoc Tests

Multiple Comparisons
Dependent Variable: Grade
Tukey HSD

(I) Conditions	(J) Conditions	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Unguided Assembly	Guided Assembly	-2.79	4.16	.78	-12.73	7.15
	Question Guided Recall	-10.15	4.28	.05	-20.38	.08

Guided Assembly	Unguided Assembly	2.79	4.16	.78	-7.15	12.73
	Question Guided Recall	-7.36	4.24	.20	-17.50	2.78
Question Guided Recall	Unguided Assembly	10.15	4.28	.05	-.08	20.38
	Guided Assembly	7.36	4.24	.20	-2.78	17.50

E.1.ii. Timepoint 2 data analysis

Descriptives
Grade

					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Min	Max
Unguided Assembly	21	30.00	15.29	3.34	23.04	36.96	5.00	60.00
Guided Assembly	23	24.96	16.99	3.54	17.61	32.30	5.00	65.00
Question Guided Recall	17	45.00	15.84	3.84	36.86	53.14	11.00	83.00
Total	61	32.28	17.86	2.29	27.71	36.85	5.00	83.00

ANOVA
Grade

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4093.31	2	2046.65	7.89	<.001
Within Groups	15036.96	58	259.26		
Total	19130.26	60			

ANOVA Effect Sizes[a]

		Point Estimate	95% Confidence Interval	
			Lower	Upper
Grade	Eta-squared	.21	.04	.37
	Epsilon-squared	.19	.01	.35
	Omega-squared Fixed-effect	.18	.01	.34
	Omega-squared Random-effect	.10	.01	.21

a. Eta-squared and Epsilon-squared are estimated based on the fixed-effect model.

Post Hoc Tests

Multiple Comparisons
Dependent Variable: Grade
Tukey HSD

		Mean	Std.		95% Confidence Interval	
(I) Conditions	(J) Conditions	Difference (I-J)	Error	Sig.	Lower Bound	Upper Bound
Unguided Assembly	Guided Assembly	5.04	4.86	.56	-6.65	16.73
	Question Guided Recall	-15.00*	5.25	.02	-27.64	-2.36
Guided Assembly	Unguided Assembly	-5.04	4.86	.56	-16.73	6.65
	Question Guided Recall	-20.04*	5.15	<.001	-32.43	-7.66
Question Guided Recall	Unguided Assembly	15.00*	5.25	.02	2.36	27.64
	Guided Assembly	20.04*	5.15	<.001	7.66	32.43

*. The mean difference is significant at the 0.05 level.

Table E.2

Experiment 5 SPSS Output Tables

E.2.i. Timepoint 1 data analysis

T-Test

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Grade	Unguided Assembly	14	78	14.24	3.81
	Mental Assembly	14	73	21.19	5.66

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means							
					Significance				95% Confidence Interval of the Difference	
Grade	F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Diff.	Std. Error	Lower	Upper
Equal variances assumed	4.078	.05	.73	26.00	.24	.47	5.00	6.82	-9.02	19.02
Equal variances not assumed			.73	22.75	.24	.47	5.00	6.82	-9.12	19.12

Independent Samples Effect Sizes

				95% Confidence Interval	
		Standardizer[a]	Point Estimate	Lower	Upper
Grade	Cohen's d	18.05	.28	-.47	1.02
	Hedges' correction	18.59	.27	-.46	.99
	Glass's delta	21.19	.24	-.51	.98

a. The denominator used in estimating the effect sizes.
Cohen's d uses the pooled standard deviation.
Hedges' correction uses the pooled standard deviation, plus a correction factor.
Glass's delta uses the sample standard deviation of the control group.

E.2.ii. Timepoint 2 data analysis

T-Test

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Grade	Unguided Assembly	13	37	13.87	3.85
	Mental Assembly	12	36	12.37	3.57

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means							
					Significance				95% Confidence Interval of the Difference	
Grade	F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
Equal variances assumed	.244	.626	.211	23	.42	.83	1.11	5.27	-9.79	12.02
Equal variances not assumed			.212	23	.42	.83	1.11	5.25	-9.74	11.97

Independent Samples Effect Sizes

				95% Confidence Interval	
		Standardizer[a]	Point Estimate	Lower	Upper
Grade	Cohen's d	13.17	.08	-.70	.87
	Hedges' correction	13.62	.08	-.68	.84
	Glass's delta	12.37	.09	-.70	.87

a. The denominator used in estimating the effect sizes.
Cohen's d uses the pooled standard deviation.
Hedges' correction uses the pooled standard deviation, plus a correction factor.
Glass's delta uses the sample standard deviation of the control group.

Table E.3

Experiment 6 SPSS Output Tables

E.3.i. Timepoint 1 data analysis

Descriptives
Grade T1

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Min	Max
Unguided Assembly	40	74.38	20.10	3.18	67.95	80.80	20.00	100.00
Free Recall	38	63.95	16.81	2.73	58.42	69.47	35.00	100.00
Neutral	38	75.13	16.66	2.70	69.65	80.61	40.00	100.00
Total	116	71.21	18.53	1.720	67.80	74.61	20.00	100.00

ANOVA

Grade

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2989.42	2	1494.71	4.63	.012
Within Groups	36491.61	113	322.94		
Total	39481.03	115			

ANOVA Effect Sizes[a,b]

		Point Estimate	95% Confidence Interval Lower	95% Confidence Interval Upper
Grade	Eta-squared	.076	.004	.172
	Epsilon-squared	.059	-.014	.157
	Omega-squared Fixed-effect	.059	-.013	.156
	Omega-squared Random-effect	.030	-.007	.085

a. Eta-squared and Epsilon-squared are estimated based on the fixed-effect model.
b. Negative but less biased estimates are retained, not rounded to zero.

Post Hoc Tests

Multiple Comparisons
Dependent Variable: Grade T1

	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Tukey HSD	Unguided Assembly	Free Recall	10.43*	4.07	.031	.76	20.10
		Neutral	-.76	4.07	.981	-10.43	8.91
	Free Recall	Unguided Assembly	-10.43*	4.07	.031	-20.10	-.76
		Neutral	-11.18*	4.12	.021	-20.98	-1.39
	Neutral	Unguided Assembly	.76	4.07	.981	-8.91	10.43
		Free Recall	11.18*	4.12	.021	1.39	20.98

*. The mean difference is significant at the 0.05 level.

E.3.ii. Timepoint 2 data analysis

Experiment 6 SPSS Analysis Timepoint 2 for Unguided Assembly, Free Recall and Neutral

Descriptives

Grade T2

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Min	Max
Unguided Assembly	36	54.27	24.23	4.04	46.07	62.47	10.00	92.00
Free Recall	37	46.61	19.58	3.22	40.08	53.14	10.00	82.00
Neutral	35	51.70	19.59	3.31	44.97	58.42	15.00	82.00
Total	108	50.81	21.29	2.05	46.75	54.87	10.00	92.00

ANOVA

Grade

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1109.81	2	554.90	1.229	.3
Within Groups	47391.14	105	451.34		
Total	48500.95	107			

ANOVA Effect Sizes[a,b]

		Point Estimate	95% Confidence Interval Lower	95% Confidence Interval Upper
Grade	Eta-squared	.11	.00	.21
	Epsilon-squared	.07	-.05	.17
	Omega-squared Fixed-effect	.07	-.04	.17
	Omega-squared Random-effect	.02	-.01	.05

a. Eta-squared and Epsilon-squared are estimated based on the fixed-effect model.

b. Negative but less biased estimates are retained, not rounded to zero.

Table E.4

Experiment 7 Secondary Schools SPSS Output Tables

E.4.i. Timepoint 1 data analysis

Descriptives
Grade

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Min	Max
Unguided Assembly	42	20.05	9.39	1.45	17.12	22.97	3.00	40.00
Guided Assembly	7	28.00	7.42	2.80	21.14	34.86	16.00	37.00
Free Recall	21	18.57	10.56	2.30	13.76	23.38	3.00	37.00
Mental Assembly	30	21.20	8.88	1.62	17.89	24.51	3.00	40.00
Neutral	30	19.90	8.70	1.59	16.65	23.15	3.00	34.00
Total	130	20.47	9.30	.82	18.86	22.08	3.00	40.00

ANOVA
Grade

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	505.83	4.00	126.46	1.48	.21
Within Groups	10650.55	125.00	85.20		
Total	11156.38	129.00			

E.4.ii. Timepoint 2 data analysis

One-way
Descriptives
Grade

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Min	Max
Unguided Assembly	30	30.18	17.51	3.20	23.64	36.72	6.00	68.80
Guided Assembly	7	51.83	15.82	5.98	37.20	66.46	37.60	77.20
Free Recall	15	42.93	20.07	5.18	31.82	54.05	9.60	77.20
Mental Assembly	21	39.61	21.30	4.65	29.91	49.30	.00	76.00
Neutral	20	33.64	18.41	4.12	25.02	42.26	.00	73.60
Total	93	36.74	19.61	2.03	32.70	40.78	.00	77.20

ANOVA
Grade

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	3825.14	4.00	956.29	2.67	.04
Within Groups	31541.96	88.00	358.43		
Total	35367.10	92.00			

ANOVA Effect Sizes[a,b]

		Point Estimate	95% Confidence Interval Lower	95% Confidence Interval Upper
Grade	Eta-squared	.11	.00	.21
	Epsilon-squared	.07	-.05	.17
	Omega-squared Fixed-effect	.07	-.04	.17
	Omega-squared Random-effect	.02	-.01	.05

a. Eta-squared and Epsilon-squared are estimated based on the fixed-effect model.
b. Negative but less biased estimates are retained, not rounded to zero.

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Grade

Tukey HSD

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Unguided Assembly	Guided Assembly	-21.65	7.95	.06	-43.78	.48
	Free Recall	-12.75	5.99	.22	-29.43	3.92
	Mental Assembly	-9.43	5.39	.41	-24.43	5.57
	Neutral	-3.46	5.47	.97	-18.68	11.76
Guided Assembly	Unguided Assembly	21.65	7.95	.06	-.48	43.78
	Free Recall	8.90	8.67	.84	-15.24	33.03
	Mental Assembly	12.22	8.26	.58	-10.79	35.23
	Neutral	18.19	8.31	.19	-4.97	41.34
Free Recall	Guided Assembly	12.75	5.99	.22	-3.92	29.43
	Unguided Assembly	-8.90	8.67	.84	-33.03	15.24
	Mental Assembly	3.32	6.40	.99	-14.50	21.15
	Neutral	9.29	6.47	.61	-8.72	27.30
Mental Assembly	Guided Assembly	9.43	5.39	.41	-5.57	24.43
	Unguided Assembly	-12.22	8.26	.58	-35.23	10.79
	Free Recall	-3.32	6.40	.99	-21.15	14.50
	Neutral	5.97	5.92	.85	-10.51	22.44
Neutral	Guided Assembly	3.46	5.47	.97	-11.76	18.68
	Unguided Assembly	-18.19	8.31	.19	-41.34	4.97
	Free Recall	-9.29	6.47	.61	-27.30	8.72
	Mental Assembly	-5.97	5.92	.85	-22.44	10.51

Grade

Tukey HSD[a,b]

Group	N	Subset for alpha = 0.05	
		1	2
Unguided Assembly	30	30.18	
Neutral	20	33.64	33.64
Mental Assembly	21	39.61	39.61
Free Recall	15	42.93	42.93
Guided Assembly	7		51.83
Sig.		.37	.08

Table E.5

Experiment 8 Postgraduate SPSS Output Tables

E.5.i. Timepoint 1 data analysis

Descriptives

Grade

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
Unguided Assembly	4	67.50	9.57	4.79	52.27	82.73	60.00	80.00
Guided Assembly	3	50.00	20.00	11.55	.32	99.68	30.00	70.00
Free Recall	5	70.00	12.25	5.48	54.79	85.21	60.00	90.00
Neutral	4	42.50	17.08	8.54	15.32	69.68	20.00	60.00
Total	16	58.75	17.84	4.46	49.24	68.26	20.00	90.00

Mann-Whitney Non-Parametric Tests

Group	Median
Unguided Assembly	65.00
Guided Assembly	50.00
Free Recall	70.00
Neutral	45.00
Total	60.00

Ranks

	Conditions	N	Mean Rank	Sum of Ranks
Grade	Unguided Assembly	4	4.88	19.50
	Guided Assembly	3	2.83	8.50
	Total	7		

Test Statistics[a]

	Grade
Mann-Whitney U	2.50
Wilcoxon W	8.50
Z	-1.26
Asymp. Sig. (2-tailed)	.21
Exact Sig. [2*(1-tailed Sig.)]	.23[b]
Exact Sig. (2-tailed)	.29
Exact Sig. (1-tailed)	.14
Point Probability	.06

Ranks

	Conditions	N	Mean Rank	Sum of Ranks
Grade	Free Recall	5	6.80	34.00
	Neutral	4	2.75	11.00
	Total	9		

Test Statistics[a]

	Grade
Mann-Whitney U	1.00
Wilcoxon W	11.00
Z	-2.25
Asymp. Sig. (2-tailed)	.02
Exact Sig. [2*(1-tailed Sig.)]	.03[b]
Exact Sig. (2-tailed)	.05
Exact Sig. (1-tailed)	.02
Point Probability	.02

Ranks

	Conditions	N	Mean Rank	Sum of Ranks
Grade	Unguided Assembly	4	4.75	19.00
	Free Recall	5	5.20	26.00
	Total	9		

Test Statistics[a]

	Grade
Mann-Whitney U	9.00
Wilcoxon W	19.00
Z	-.26
Asymp. Sig. (2-tailed)	.79
Exact Sig. [2*(1-tailed Sig.)]	.90[b]
Exact Sig. (2-tailed)	.83
Exact Sig. (1-tailed)	.45
Point Probability	.14

Ranks

	Conditions	N	Mean Rank	Sum of Ranks
Grade	Unguided Assembly	4	6.25	25.00
	Neutral	4	2.75	11.00
	Total	8		

Test Statistics[a]

	Grade
Mann-Whitney U	1.00
Wilcoxon W	11.00
Z	-2.07
Asymp. Sig. (2-tailed)	.04
Exact Sig. [2*(1-tailed Sig.)]	.06[b]
Exact Sig. (2-tailed)	.09
Exact Sig. (1-tailed)	.04
Point Probability	.04

Ranks

	Conditions	N	Mean Rank	Sum of Ranks
Grade	Guided Assembly	3	4.50	13.50
	Neutral	4	3.63	14.50
	Total	7		

Test Statistics[a]

	Grade
Mann-Whitney U	4.50
Wilcoxon W	14.50
Z	-.54
Asymp. Sig. (2-tailed)	.59
Exact Sig. [2*(1-tailed Sig.)]	.63[b]
Exact Sig. (2-tailed)	.69
Exact Sig. (1-tailed)	.37
Point Probability	.11

Ranks

	Conditions	N	Mean Rank	Sum of Ranks
Grade	Unguided Assembly	3	3.00	9.00
	Free Recall	5	5.40	27.00
	Total	8		

Test Statistics[a]

	Grade
Mann-Whitney U	3.00
Wilcoxon W	9.00
Z	-1.38
Asymp. Sig. (2-tailed)	.17
Exact Sig. [2*(1-tailed Sig.)]	.25[b]
Exact Sig. (2-tailed)	.20
Exact Sig. (1-tailed)	.12
Point Probability	.07

E.5.ii. Timepoint 2 data analysis

Descriptives

Grade

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Min	Max
Unguided Assembly	4	46.02	16.29	8.14	20.10	71.94	25.45	59.09
Free Recall	4	43.64	13.75	6.87	21.76	65.51	30.91	62.73
Neutral	4	39.21	19.32	9.66	8.46	69.95	18.18	63.64
Total	12	42.95	15.31	4.42	33.23	52.68	18.18	63.64

Group	Median	Skewness
Guided Assembly	49.77	-.681
Free Recall	40.46	1.190
Neutral	37.50	.453
Total	42.05	.028

Mann-Whitney Non-Parametric Tests

Ranks

	Conditions	N	Mean Rank
Grade	Unguided Assembly	4	4.50
	Free Recall	4	4.50
	Total	8	

Test Statistics[a]

	Grade
Mann-Whitney U	8.00
Wilcoxon W	18.00
Z	.00
Asymp. Sig. (2-tailed)	1.00
Exact Sig. [2*(1-tailed Sig.)]	1.00[b]
Exact Sig. (2-tailed)	1.00
Exact Sig. (1-tailed)	.53
Point Probability	.06

Ranks

	Conditions	N	Mean Rank	Sum of Ranks
Grade	Unguided Assembly	4	4.75	19.00
	Neutral	4	4.25	17.00
	Total	8		

Test Statistics[a]

	Grade
Mann-Whitney U	7.00
Wilcoxon W	17.00
Z	-.29
Asymp. Sig. (2-tailed)	.77
Exact Sig. [2*(1-tailed Sig.)]	.89[b]
Exact Sig. (2-tailed)	.83
Exact Sig. (1-tailed)	.41
Point Probability	.04

Ranks

	Conditions	N	Mean Rank	Sum of Ranks
Grade	Free Recall	4	4.63	18.50
	Neutral	4	4.38	17.50
	Total	8		

Test Statistics[a]

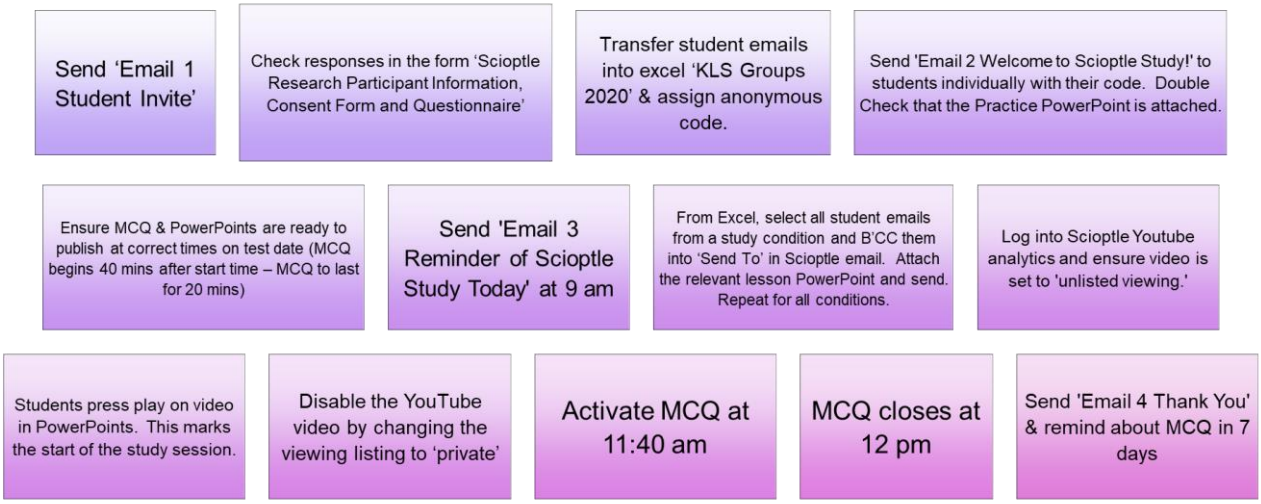
	Grade
Mann-Whitney U	7.50
Wilcoxon W	17.50
Z	-.15
Asymp. Sig. (2-tailed)	.88
Exact Sig. [2*(1-tailed Sig.)]	.89[b]
Exact Sig. (2-tailed)	.97
Exact Sig. (1-tailed)	.49
Point Probability	.09

Appendix F

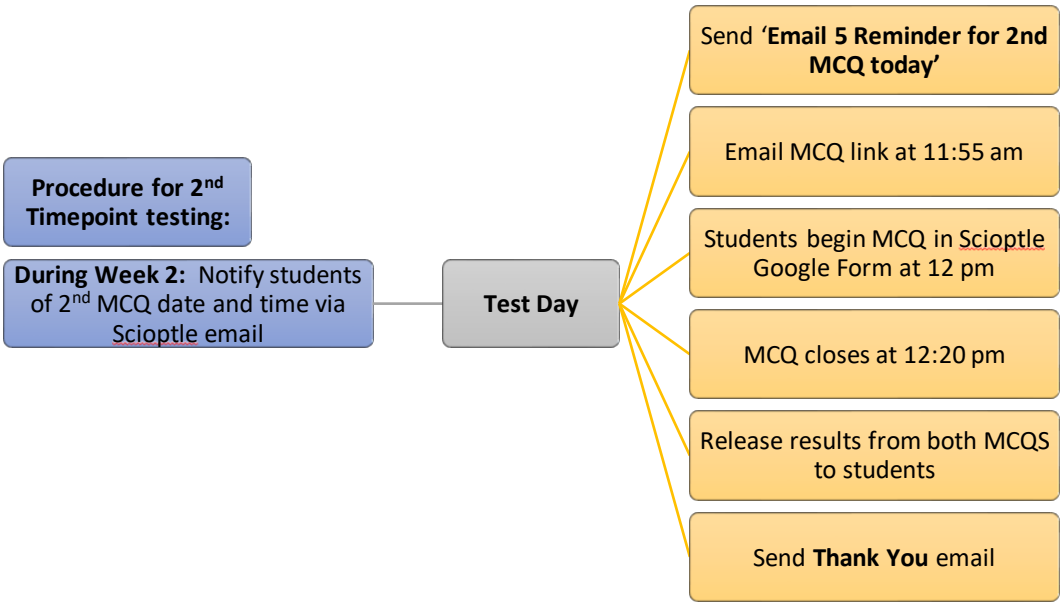
Figure F.1

Flowchart for Two Timepoint Study

Timepoint 1:



Timepoint 2:



Appendix G

The suitability of KLS as a Qualitative Research Project

Below is a set of 12 tips (McGrath, Palmgren & Liljedahl, 2019), that summarise and synthesise best practice guidelines from a range of studies into qualitative research, as it relates to medical and life science education. These align with Coursera's 'Qualitative Research Methods'. I've included direct quotes from each 'tip' and briefly discussed the relevance of doing KLS as a qualitative research project, based on the recommendations for conducting qualitative research.

1) Identify whether a qualitative research approach is suitable, as:

"One should consider the ethical dimensions of taking up time from interviewees and therefore only include as many participants as needed in the research project and who may have insights or experiences of the phenomenon in question…. Qualitative research interviews are preferable when the researcher strives to understand the interviewee's subjective perspective of a phenomenon rather than generating generalizable understandings of large groups of people."

None of the potential study participants we interview will have prior knowledge of either the science topic, or the interactive approach we are trialling. We are proposing new methods which no-one can provide feedback on without first participating in testing those methods. We need a large volume of students to accurately reflect and generalise the efficacy of the online approaches to be tested, especially if the study is to be scaled up or down and expanded outside UCC. Therefore, doing the study as a qualitative project is not going to address, or fulfil, the scope and objectives of our research.

2) What is the scope and focus of the research question?

"Successful interviews start with careful planning that considers the focus and scope of the research question…. The venue of the interview should also be considered as it may affect the data collection. We recommend interviews be conducted at a time and place of the respondents' convenience, in a comfortable setting, free from any potential disruptions and noise. In most cases, you will need formal ethical approval. However, you will always need your interviewees' informed consent (Illing, 2014)."

The main objectives of our study are to identify, design and investigate novel approaches and tools for facilitating kinaesthetic learning of educational content online. In order to do this, we must have students test the approaches and tools developed. Our long-term goal was also to develop a suite of learning tools and build them into a substantial repository of online KLS approaches – this cannot be done by converting to a qualitative project, but qualitative analysis of each approach after testing is vital to identify any anomalies along the way or in MCQ results, e.g., technical difficulties etc.

The venue for conducting qualitative interviews is a pretty big consideration by all sources of qualitative research. The same uncertainty exists for using the qualitative approach at the moment with regards the lockdown as it does for the current stage we are at in our study, i.e., recruiting students to online face-to-face interviews will be as problematic as recruiting them for any aspect of the KLS study. However, selecting a sample of students to complete survey style questions for student feedback following a test are sufficient to qualify as qualitative research when in the context of validating a quantitative approach that has been used on a larger student population.

In qualitative studies where many interviews are conducted, the person interviewed is generally entitled to view the transcripts of their interview to validate the interviewer's interpretation of their responses. This would be problematic for the time-flow of the KLS study and may lead to unnecessary interference in the analysis of results.

3) Choosing between interview styles, e.g., structured vs. semi-structured

"The style of the interview is essential for creating a non-invasive and open dialog with interviewees (Krag Jacobsen 1993). Avoid using esoteric jargon in your research interview questions and instead adopt layman's language when possible…. It is important that the interview guide aligns with the methodological approach (Laksov et al. 2017)…. In medical education, semi-structured interviews are often applied, meaning that the interview guide includes a number of predetermined questions (typically 5–15 questions) but the interviewer can probe, in order to dig deeper, into the interviewees' responses through follow-up questions (Lingard and Kennedy 2010)."

The emails I sent to students thanking them were friendly, peer-like and worded casually to keep good rapport and encourage feedback. This worked well as the two students in particular that I asked for further feedback (based on initial feedback), both responded very quickly, with more detailed and pointed feedback. This was quite an unstructured approach but not far from the semi-structured model, which encourages question formation to a certain extent, to be formed from the respondent's answers. Taking a sample of students from the larger student population tested with KLS approaches, and conducting individual, face-to-face, semi-structured interviews would be valuable going forward – for feedback purposes. Therefore, to build rapport with students at short notice, the continued use of very informal, peer-like language in all communication, would most likely encourage participation in tests.

4) Be aware of the cultural and power dimensions of interviews

"People are cultural beings (Rogoff 2003) and may have different expectations of the interview situation. Some people may view the interview as a difficult or invasive situation, and some interviews may require a third person to sit in, either as an interpreter or as someone who is culturally sensitive to the interviewees' situation…. Teachers interviewing students need to be aware of both explicit and implicit power relationships and be conscious that students are not trying to comply with expectations of providing, what is perceived to be, a correct response."

The use of email for getting quick feedback in the last test worked very well for keeping the informal aspect going and the answers received were very direct and honest (as some students reported they found it difficult) and so, removed some of the concern about the power dynamic. The fact that some students chose not to respond at all to any feedback requests, inadvertently confirms this approach is non-invasive or intimidating from a power-role dynamic, i.e., the students did not feel pressured to respond to the teachers.
Again, to avoid power-roles dominating any aspect of the study going forward, informal communication would be wise to ensure honest, unbiased feedback down the road.

5) Build rapport

"Building rapport and establishing comfortable interactions in the qualitative interview situation is very important and is preferably done well in advance of the interview…. there may be little time in the interview situation to build trust (DiCicco-Bloom and Crabtree 2006). Therefore, you should draft a short summary of your research project, written in layman's terms, to send to your interviewees prior to the interview as a way of informing them of what to expect will be talked about in the interview and why it is an important topic to discuss…. Rapport is also crucial during the interview enabling the

respondent to provide a rich and detailed account of the experiences at the heart of the study. Key to building rapport is a sense of proximity. If you already know your respondents, then it may be easier to build rapport; otherwise, this task may be more difficult."

Looking back over the Participant Information Form, the language does appear quite formal. I received a very good participant info form from a psychology post-grad whose study I took part in recently – the language and layout were simple and to the point. We could loosely re-model our Participant info on this and keep it as short and to the point as possible.

6) The researcher is the prime instrument of data collection

"In the qualitative research interview, we argue that the interviewer should not be viewed as someone contaminating or biasing the data, but rather as a co-creator of data together with the interviewee, where the interviewer's previous knowledge may play an important part in understanding of the context or the experiences of the interviewee."

Not a practical view to take in our study as we are creating content and interactive approaches that are necessarily 'biased' towards current best practice in e-learning and looking for direct feedback on this work, rather than discussing some philosophical topic or past/current education experiences. We are testing something new and exploratory, based on our informed opinions and so, there is already bias in that respect and the student's opinions, while valuable for feedback, are not informed in current education research – we cannot co-create beyond the point of taking feedback on board.

7) Allow the interviewee to talk

"Interviewers may need to talk less and allow for silence to act as the catalyst that will drive the conversation forward. Actively listening to the interviewees means respecting silence and identifying such silent moments as an opportunity for ongoing reflection."

Again, this is when both parties are exploring a somewhat philosophical topic, e.g., 'What is happiness?' We will be able to draw more questions from respondent's answers but our questions are more analytical rather than philosophical. However, we might consider whether it would be helpful at some point to add a question or two at the end of an interview, on how the student sees the role of technology as helping or harming education and so forth.

8) Allow yourself to adjust the interview guide

"Adjusting the questions after the initial interviews allows the interview guide to be fine-tuned during the interview process. Some questions might turn out to be misunderstood, others to be irrelevant or outside the scope of the research question. In one of our own studies, for example, the question "How do you experience the atmosphere here?" was understood by students as a question about the physical environment and the quality of the air, while the intention of the interviewer was to gain insight into the social environment in the clinic (Liljedahl, et al., 2015)."

The questions in the second round of emails for feedback were adjusted from the original prompts, as they were based on the information received from the students. This is common sense and would have to be applied to most interviews in any case. We can draft our interview prior to the next study and receive feedback on it to ensure all the questions are unambiguous.

9) Emotions in interviews

"The interviewer must be sensitive to the interviewee's reactions when sharing experiences on certain topics….. Invite the interviewee to bring up issues of the topic that are important to him or her, and always end the interview by asking the interviewee if there is anything they would like to add regarding the topic of interest in the interview."

Again, our current approach to get qualitative feedback takes this into account and have already re-modelled the PowerPoints, both from feedback from the first pilot study and from the latest in May. As regards ethically dealing with emotions, this was also achieved recently. For example, one student in particular felt he had done bad overall in the Lac Operon lesson, with the valid excuses that the topic was new to him and that he had had technical problems viewing the PowerPoint. I got the impression he was doubtful of his own ability to learn, which is counteractive to him as a student going forward and not a desirable out-come from testing students. I emailed him and praised him for his perseverance in-spite of all the challenges and advised him this trait is one that would stand to him well, beyond the walls of university, rather than focusing on any single MCQ result. Again, I put the MCQ in the context that the success of our learning approach would be reflected by group results and that feedback from the students on the interaction and lesson itself was as important a factor as the MCQ.

I think it will be important for us to highlight the context of the lessons to students, in that we are using advanced topics to test our learning approaches, not to test their intellect as students. This should be put into context in the very first communication with them and repeated throughout, so the testing itself does not have any negative emotional effect on them or reduce their self-esteem in any way.

10) Transcribe the interviews in good time

"The most common form of transcription in qualitative interviews is verbatim transcription, which refers to the word-for-word reproduction of verbal data, where the written words are an exact replication of the audio-recorded words (Poland 1995). Transcribing data from qualitative interviews is very time-consuming…. initial transcription may require as much as four to eight hours of transcription for each hour of recorded data. Furthermore, the process yields vast amounts of material which must be iteratively scrutinized and waded through when analyzing the data…. It is important to consider pauses, giggles, and other cues offered by the interviewee as markers for important events in the interview. These cues may need to be acknowledged…. Many investigators choose to transcribe the qualitative interviews themselves even though that is time-consuming and arduous…. Doing so allows the researcher to start identifying analytical structures and find similarities and differences between different interviewees' experiences.

This is very true – one interview I conducted for Coursera led to huge volumes of information - if you are doing qualitative research for publishing, you must identify the methods and views (ontological, epistemological, interview as a topic or a theme etc.) you took, the framework you developed for dividing answers into themes, headings and sub-headings and then, the analysis of your own role and behaviour as an interviewer, as well as the behaviour of the interviewee. All this has to be described in the context of the venue, the background, the topic, the rapport, the depth of the relationship between both parties and more. Body language must be described as well as notes made of any probing techniques used by the interviewer that may have led the interview to veer in any particular direction and any off-transcript behaviour, e.g., interviewee fidgeting, looking around, giggling etc. –

these responses generally must be analysed to put the answers into context. Instead, it would be worth having a set of feedback surveys/questionnaires to deliver immediately post-test but also, to randomly invite a percentage (~10%?) of students to do an online, face-to-face, individual interview via zoom within a day or two after the test.

11) Validating the study

"Member checking is a method of returning an interview transcript or debriefing the analytical results with participants for agreement (Lincoln and Guba 1985; Creswell 2013)…. a way of checking that one has understood the reported responses of the respondents…. some researchers recommend caution with reference to member checking, as there may be some potential drawbacks such as conflicting views on interpretation (Angen 2000; Morse et al. 2002; Varpio et al. 2017).

This would be more in relation to philosophical or general topics rather than to the pointed feedback we are seeking from testing KLS. However, allowing students to access or modify their responses from any face-to-face interviews is something we have to bear in mind.

12) Begin analysis early

"One of the main difficulties with qualitative research is that it very rapidly generates a large and cumbersome amount of data, often leading to hundreds of pages of transcribed text. Miles (1979) has depicted qualitative data as an "attractive nuisance"; it has attractiveness due to its richness, but effort is required to find analytical paths through that richness. Therefore, you will need to think about the analysis of data before conducting all the interviews. The nature of the research question(s) and how you go about the analysis will determine the depth, quality, and richness of the performed interviews. Hence, we advise that the analysis of the material is not left until all interview data has been transcribed."

This style of research would be suitable for anthropological studies and the like but would not be suitable as a project for a scientific study that relies heavily on quantitative data of a technique. We are trying to analyse whether a certain online approach does or does not work, so we are looking for definitive answers. A qualitative project would look for possibilities for changing education techniques or opinions on current techniques, rather than the definitive answers we are after and so, would not be suitable as the main research approach for KLS – we need the scientific approach more than the qualitative, but the qualitative feedback will help validate and interpret the scientific approach.