## Detailed contents

Acknowledgements............................................................................................................. 15

Abstract.................................................................................................................................... 17

Abbreviations.......................................................................................................................... 18

1 Introduction and literature review ...................................................................................... 20

1.1 Introduction...................................................................................................................... 20

1.1.1 Why evolution? ............................................................................................................ 20

1.1.2 Why genetics? .............................................................................................................. 20

1.1.3 Why me? ..................................................................................................................... 21

1.1.4 Terminology ................................................................................................................ 22

1.1.5 Research questions ..................................................................................................... 23

1.1.6 Thesis structure .......................................................................................................... 23

1.2 Literature review............................................................................................................. 25

1.2.1 Introduction to evolution acceptance, understanding, and education ..................... 25

1.2.2 Challenges to understanding, accepting and teaching evolution ......................... 27

1.2.2.1 Student Factors ..................................................................................................... 28

1.2.2.2 Teacher Factors ..................................................................................................... 32

1.2.2.3 Subject factors ...................................................................................................... 33

1.2.3 Approaches to teaching evolution .............................................................................. 35

1.2.3.1 Approaches to teaching a controversial topic ....................................................... 36

1.2.3.2 Evolution teaching strategies: prior knowledge, content and context .................. 40

1.2.3.3 Teaching activities and resources ......................................................................... 45

1.2.4 Teaching genetics ...................................................................................................... 48

1.2.5 Evolution and genetics in the UK .............................................................................. 49

1.2.6 Limitations and conclusions ...................................................................................... 50

2 Methodology ..................................................................................................................... 52

2.1 Student questionnaire .................................................................................................... 53

2.1.1 Evolution acceptance ................................................................................................. 55

2.1.2 Genetics knowledge ................................................................................................. 56
2.1.3 Evolution knowledge................................................................. 57
2.1.4 Pilot study ................................................................................. 58
2.1.5 Development of the questionnaire .............................................. 61
2.1.6 Recruitment of schools ................................................................. 64
2.1.7 Data overview ............................................................................ 65
2.1.8 Background information ............................................................... 67
2.2 Focus groups .................................................................................. 67
2.2.1 Question development ................................................................. 67
2.2.2 Pilot study ................................................................................... 68
2.2.3 Conducting focus groups ............................................................... 69
2.2.4 Data collection and input ............................................................... 70
2.3 Teacher interviews .......................................................................... 70
2.4 Teacher surveys ............................................................................... 71
2.4.1 Design of the teacher survey ....................................................... 71
2.4.2 Distribution of the survey .............................................................. 72
2.4.3 Data collection ............................................................................. 73
2.5 Data analysis ................................................................................... 73
2.5.1 Key variables ............................................................................. 74
2.5.1.1 Academic ability ................................................................. 74
2.5.1.2 Topic order ........................................................................... 75
2.6 Ethical considerations and data protection ...................................... 76
2.6.1 Student questionnaires ................................................................. 76
2.6.2 Student focus groups ................................................................. 77
2.6.3 Teacher surveys ........................................................................... 77
2.7 Summary ....................................................................................... 78

3 Analysis of the student questionnaire ............................................. 79
3.1 Reliability ....................................................................................... 80
3.1.1 Evolution acceptance ................................................................. 80
3.1.1.1 Reliability of individual items ............................................... 81
3.1.1.2 Reliability of aspects of evolution ........................................ 82
3.1.2 Genetics and evolution knowledge ............................................. 88
3.2 Item difficulty ................................................................................. 89
3.3 Item non-response .......................................................................... 92
3.4 Validity ......................................................................................... 97
4 Pre test results ........................................................................................................ 100
  4.1 Students accept evolution ................................................................................ 101
    4.1.1 Students accept different aspects of evolution ......................................... 102
    4.1.2 Higher ability students have greater acceptance of evolution ............... 103
  4.2 Students have some understanding of genetics .............................................. 104
    4.2.1 Variation in student knowledge of genetics ............................................. 105
    4.2.2 Higher ability students have more knowledge of genetics .................... 108
  4.3 Students have little knowledge of evolution .................................................. 108
    4.3.1 Variation in student knowledge of evolution ......................................... 109
    4.3.2 Higher ability students have more knowledge of evolution ............... 110
  4.4 Relationships between knowledge and acceptance ...................................... 110
    4.4.1 Knowledge of genetics is positively correlated to acceptance of evolution .................................................................................. 111
    4.4.2 Knowledge of genetics is weakly correlated to understanding of evolution .................................................................................. 112
    4.4.3 Knowledge of evolution is weakly correlated to acceptance of evolution .................................................................................. 112
  4.5 Summary and implications for teaching ....................................................... 114

5 Post test results .................................................................................................... 115
  5.1 The impact of teaching ..................................................................................... 116
    5.1.1 Teaching has a positive impact on evolution acceptance ....................... 116
      5.1.1.1 Students accept different aspects of evolution .................................. 119
    5.1.2 Teaching has a positive impact on knowledge ........................................ 120
  5.2 Academic ability ............................................................................................. 122
    5.2.1 Higher ability students have greater acceptance of evolution ............... 122
    5.2.2 Higher ability students have more knowledge of genetics .................... 123
    5.2.3 Higher ability students have more knowledge of evolution .................. 124
  5.3 Topic order ..................................................................................................... 125
    5.3.1 Teaching genetics first increases genetics knowledge ............................ 126
    5.3.2 Teaching genetics first increases evolution knowledge .......................... 126
5.3.3 Topic order has no impact on evolution acceptance ................................. 128
5.4 Ability and topic order .................................................................................. 128
5.4.1 Teaching genetics first increases evolution knowledge for higher and lower ability students .............................................................. 129
5.4.2 Teaching genetics first increases genetics knowledge for higher and lower ability students .............................................................. 130
5.4.3 Topic order has no impact on evolution acceptance ................................. 131
5.5 Relationships between acceptance and understanding .............................. 132
5.6 Summary and implications for teaching ....................................................... 135

6 Retention test results .................................................................................... 137
6.1 The lasting impact of teaching .................................................................... 138
6.1.1 Teaching has a lasting impact on evolution acceptance ....................... 141
6.1.1.1 Students accept different aspects of evolution .................................. 145
6.1.2 Teaching has a lasting impact on genetics knowledge but misconceptions persist ........................................................................ 146
6.1.3 Teaching has a lasting impact on evolution knowledge but misconceptions persist ........................................................................ 150
6.2 Ability and topic order ................................................................................ 152
6.2.1 Teaching has a lasting impact on students of different abilities .......... 152
6.2.2 Topic order ................................................................................................ 157
6.3 Relationships between acceptance and understanding ............................ 158
6.4 Summary and implications for teaching ....................................................... 161

7 Focus groups .................................................................................................. 162
7.1 Key questions ............................................................................................. 163
7.1.1 What does ‘evolution’ make students think of? ..................................... 163
7.1.2 How do students know about evolution before secondary school? ...... 164
7.1.3 What are students’ views on learning about evolution? ....................... 168
7.1.3.1 Evolution lessons .............................................................................. 168
7.1.3.2 Enjoyment and interest .................................................................... 171
7.1.3.3 The importance of learning about evolution .................................. 172
7.1.3.4 Unanswered questions .................................................................... 174
7.1.3.5 Evolution in primary schools .......................................................... 175
7.1.3.6 Evolution appears to be different to other scientific theories .......... 178
**Figures**

**Figure 2.1** Examples of questions used to assess students’ acceptance of evolution in the student questionnaire ......................................................... 56

**Figure 2.2** Example of a question used to assess student understanding of evolution ........................................................................................................... 58

**Figure 2.3** Correct answers for knowledge questions in the pilot study ........... 59

**Figure 2.4** Responses to the feedback statements in the pilot study ............... 60

**Figure 2.5** Question 21 in the pilot questionnaire ........................................ 62

**Figure 3.1** Item 6 in the student questionnaire ............................................. 82

**Figure 3.2** Geological time items used to assess students’ acceptance of evolution in the student questionnaire ................................................................. 83

**Figure 3.3** Overall evolution acceptance responses ...................................... 84

**Figure 3.4** Bar charts showing overall percentage of responses to evolution acceptance items .................................................................................................. 86

**Figure 4.1** Evolution acceptance of students, before learning about evolution ......................................................................................................................... 101

**Figure 4.2** Combined evolution acceptance of students, before learning about evolution ........................................................................................................ 101

**Figure 4.3** Evolution acceptance for the seven different aspects of evolution ... 102

**Figure 4.4** Comparison of proportion of evolution acceptance between higher and lower ability students ................................................................. 103

**Figure 4.5** Acceptance of evolution for higher and lower ability students ...... 104

**Figure 4.6** Understanding of genetics, before teaching ................................. 104

**Figure 4.7** Understanding of genetics for higher and lower ability students, prior to learning about genetics ................................................................. 108

**Figure 4.8** Understanding of evolution, before teaching .............................. 109

**Figure 4.9** Understanding of evolution, for higher and lower ability students, prior to learning about evolution ................................................................. 110

**Figure 4.10** The relationship between evolution acceptance and genetics knowledge .................................................................................................................. 111

**Figure 4.11** The relationship between evolution knowledge and genetics knowledge ................................................................................................................. 112

**Figure 4.12** The relationship between evolution acceptance and evolution knowledge ............................................................................................................. 113
Figure 5.1 Evolution acceptance categories, after teaching.................................116
Figure 5.2 Combined evolution acceptance categories, before and after learning
about evolution and genetics.................................................................117
Figure 5.3 Change in evolution acceptance due to teaching...............................118
Figure 5.4 Evolution acceptance for the seven different aspects of evolution, after
teaching.................................................................................................119
Figure 5.5 Acceptance of evolution, before and after teaching............................120
Figure 5.6 Understanding of genetics, before and after teaching..........................121
Figure 5.7 Acceptance of evolution for higher and lower ability students, before
and after learning about evolution and genetics........................................123
Figure 5.8 Understanding of genetics for higher and lower ability students, before
and after learning about evolution and genetics........................................124
Figure 5.9 Change in understanding of evolution for different topic orders, after
teaching.................................................................................................126
Figure 5.10 Understanding of genetics for different topic orders, before and after
learning about evolution and genetics......................................................127
Figure 5.11 Change in understanding of genetics for different topic orders, after
teaching.................................................................................................127
Figure 5.12 Change in understanding of evolution due to teaching for higher
ability students taught genetics first and evolution.......................................129
Figure 5.13 Change in understanding of evolution due to teaching for lower
ability students taught genetics first and evolution.......................................130
Figure 5.14 Correlation between acceptance of evolution and understanding of
genetics, before and after learning about evolution and genetics.................133
Figure 5.15 Correlation between understanding of evolution and understanding of
genetics, before and after learning about evolution and genetics.................133
Figure 5.16 Correlation between acceptance of evolution and understanding of
evolution, before and after learning about evolution and genetics..............134
Figure 6.1 Pre, post, and retention test scores for evolution acceptance, genetics
knowledge, and evolution knowledge.........................................................139
Figure 6.2 Changes in pre, post, and retention test scores for evolution
acceptance, genetics knowledge, and evolution knowledge..........................140
Figure 6.3 Overall student acceptance of evolution at the three questionnaire
times.........................................................................................................141
Figure 6.4 Student acceptance of evolution at the three questionnaire times ..... 142
Figure 6.5 Change in evolution category between pre and post tests ............. 144
Figure 6.6 Change in evolution category between post and retention tests ...... 144
Figure 6.7 Change in evolution category between pre and retention tests .... 144
Figure 6.8 Acceptance of different aspects of evolution, three to six months after teaching .................................................................................................................. 145
Figure 6.9 Knowledge of genetics, three to six months after teaching .......... 146
Figure 6.10 Knowledge of evolution, three to six months after teaching .... 150
Figure 6.11 Evolution acceptance for higher and lower ability students at the three questionnaire times ................................................................. 154
Figure 6.12 Genetics knowledge for higher and lower ability students at the three questionnaire times .................................................................................. 155
Figure 6.13 Evolution knowledge for higher and lower ability students at the three questionnaire times ............................................................................. 156
Figure 6.7 Acceptance of evolution and understanding of genetics before, immediately after, and three to six months after teaching ................... 159
Figure 6.8 Acceptance of evolution and understanding of evolution before, immediately after, and three to six months after teaching .................... 159
Figure 6.9 Understanding of evolution and understanding of genetics before, immediately after, and three to six months after teaching ............. 160
Figure 7.1 Word cloud showing what first comes to mind when students hear the word ‘evolution’ ................................................................. 162
Figure 7.2 Word cloud showing frequently used words during all 16 focus groups ................................................................................................. 197
Figure 8.1 Acceptance of evolution among secondary school science teachers ................................................................................................. 217
Figure 8.2 Proportion of evolution acceptance among teachers ............ 217
Figure 8.3 Acceptance of different aspects of evolution among teachers .... 218
Figure 8.4 Understanding of evolution among secondary school science teachers ................................................................................................. 219
Figure 8.5 Understanding of genetics among secondary school science teachers ................................................................................................. 221
Figure 8.6 Evolution acceptance and understanding of genetics among secondary school science teachers ............................................................... 224
Figure 8.7 Understanding of evolution and understanding of genetics among secondary school science teachers .......................................................... 225
Figure 8.8 Acceptance of evolution and understanding of evolution among secondary school science teachers .......................................................... 225
Figure 8.9 Secondary science teachers’ confidence in teaching general science and in teaching evolution .......................................................... 226
Figure 8.10 Acceptance of evolution among pre-service secondary school science teachers ........................................................................ 228
Figure 8.11 Proportion of evolution acceptance among pre-service teachers ... 228
Figure 8.12 Acceptance of different aspects of evolution among pre-service teachers ........................................................................ 229
Figure 8.13 Understanding of evolution among pre-service secondary school science teachers ........................................................................ 230
Figure 8.14 Understanding of genetics among pre-service secondary school science teachers ........................................................................ 233
Figure 8.15 Understanding of genetics and acceptance of evolution among pre service teachers ........................................................................ 236
Figure 8.16 Understanding of genetics and understanding of evolution among pre service teachers ........................................................................ 237
Figure 8.17 Acceptance of evolution and understanding of evolution among pre service teachers ........................................................................ 237
Figure 8.18 Pre-service secondary science teachers’ confidence in teaching general science and in teaching evolution ........................................ 238
Figure 8.19 Evolution acceptance, evolution understanding, and genetics understanding for teachers and pre-service teacher ............................. 240
Tables

Table 2.1 Aspects of evolution ................................................................. 55
Table 2.2 Readability of the different sections of the student questionnaire ...... 63
Table 2.3 Overview of student questionnaire data collected .......................... 66
Table 2.4 Sample sizes for variables of key interest ..................................... 66
Table 3.1 Internal consistency of evolution acceptance items ......................... 80
Table 3.2 Reliability if an item is deleted and item-rest correlation between each item and all other items ...................................................... 81
Table 3.3 Internal consistency for aspects of evolution ................................... 83
Table 3.4 Skew of each evolution acceptance item ......................................... 88
Table 3.5 Internal consistency of genetics knowledge items ............................ 88
Table 3.6 Internal consistency of evolution knowledge items .......................... 89
Table 3.7 Item difficult for genetics and evolution knowledge questions .......... 91
Table 3.8 Percentage item non-response ..................................................... 93
Table 3.9 Strategies considered for dealing with non-response items ............... 96
Table 4.1 Categorisation of evolution acceptance ......................................... 101
Table 4.2 Genetics knowledge before teaching ............................................ 106
Table 4.3 Evolution knowledge before teaching ........................................... 109
Table 5.1 Change in acceptance of evolution following teaching .................... 120
Table 5.2 Change in understanding of genetics and of evolution following teaching ................................................................................. 121
Table 5.3 Proportions of change in acceptance of evolution, understanding of genetics and understanding of evolution, following teaching ................ 122
Table 5.4 Proportions of higher and lower ability students taught genetics first and evolution first ..................................................................... 129
Table 5.5 Correlations between evolution acceptance, genetics knowledge, and evolution knowledge ................................................................. 134
Table 5.6 Partial correlations ....................................................................... 134
Table 6.1 Genetics knowledge three-six months after teaching ......................... 148
Table 6.2 Evolution knowledge three-six months after teaching ...................... 151
Table 6.3 Partial correlations ....................................................................... 160
Table 8.1 Evolution knowledge of teachers ................................................... 220
Table 8.2 Genetics knowledge of teachers ..................................................... 222
Table 8.3 Evolution knowledge of pre-service teachers .................................. 232
Table 8.4 Genetics knowledge of pre-service teachers........................................234
Table 9.1 Suggestions for evolution teaching resources and activities from secondary school teachers.................................................................245
Table 9.2 Suggestions for genetics teaching resources and activities from secondary school teachers.................................................................247
Acknowledgments

Collaborator contribution
Unless otherwise stated, this thesis is my own work. I processed and analysed all of the data and interpreted the results, with the help of my supervisor, Laurence D Hurst.

The teacher survey (Chapter 8) is a joint research venture with Loredana Buchan, a PhD student at the University of Bath who is researching how best to teach evolution in primary schools. Questions for the survey were developed collaboratively but the survey layout was designed and input to ‘SurveyMonkey’ ([www.surveymonkey.net](http://www.surveymonkey.net)) by myself. Within this thesis, only data from secondary science teachers and secondary science pre service teachers are included. All analyses and interpretations are my own, with support from Laurence D Hurst.

Research instruments used within this study have been developed or taken inspiration from previous work. These are detailed and referenced within the relevant sections of this thesis. Permissions have been granted from the publishers of the main research papers upon which the research instruments devised here are based. These permissions are to reuse aspects of the works of Rutledge and Warden (1999), Lewis and Wood-Robinson (2000), Anderson et al. (2002) and Lovely and Kondrick (2008) within research questionnaires in paper and electronic forms, and for inclusion within this thesis.

Funding
This work has been funded by the Evolution Education Trust.
There are so many people who deserve my gratitude and without whom this thesis would not exist. I wish to offer my sincere thanks…

… to Jonathan. Without your inspiration this project would not have been initiated. I can never thank you enough for giving me this opportunity, for your generosity, and for allowing me the time and space to think.

… to my supervisors: Laurence, for your insight and clear vision, and also for your kindness and support; Momna, for your ever welcoming smile, advice, and encouragement; and Paul, for your educational perspectives.

… to those teachers, students and coordinators who welcomed me into schools: without you this research could not have happened. I truly hope this has and will benefit you.

… to everyone at the University of Bath for their assistance, support and patience. Especially Dana and Lis, for your friendship and advice, and all in 4 South office 0.13, past and present. I feel honoured to have worked alongside such fascinating minds. I apologise for distracting you!

… to my family for providing me with education and igniting a desire to learn, my friends who have supported me, and last but definitely not least,

_for Alfie_
Abstract

What is the best way to teach evolution? Despite its importance, evolution is widely recognised as one of the most misunderstood topics in biology. Its eminent position within science is not fully recognised in schools and there are concerns over its unsatisfactory teaching. Many students have difficulty in accepting evidence for the theory of evolution and debate is currently in progress about how best to teach evolution in secondary schools. The GEVOteach project aims to investigate how and why acceptance of evolution may alter for school students during their education and, in particular, how knowledge of genetics may contribute to understanding and acceptance of evolution. Prior research suggests a relationship between evolution and genetics exists. In the UK, these are typically taught to 14 to 16 year old school students as separate topics with few links. Here, we report the results of a randomised trial into teaching order of these topics. A questionnaire to ascertain students’ acceptance of evolution and understanding of evolution and genetics has been developed and data have been collected from over 1850 students. We report that teaching genetics first has a marked and significant impact on both evolution and genetics knowledge. This suggests a simple intervention; teaching genetics first, will improve results. However, we find only weak or moderate correlations between knowledge and acceptance. Reasons for this apparent dislocation are unclear. Qualitative data collected from focus groups suggests that not what is taught, but who evolution is taught by, is more important for acceptance. Academic ability is shown to be important in student acceptance of evolution and understanding of genetics and evolution. Teaching has a positive effect on acceptance and knowledge, but not for all students.
Abbreviations

A Level – Advanced Level
*A General Certificate of Education* Advanced Level qualification completed in the UK over two years and typically studied between the ages of 16 and 18. The term A Level is sometimes used to refer specifically to the second or A2 year of the course.

AS Level – Advanced Subsidiary Level
*The first year of the A Level qualification*, typically studied between the ages of 16 and 17. It is also a qualification within its own right.

ASE – Association for Science Education
*A professional body for those involved in science education in the UK.*

CINS – Conceptual Inventory of Natural Selection
*An instrument designed by Anderson et al. (2002) to assess undergraduate students’ understanding of natural selection.*

GCSE – General Certificate of Secondary Education
*A UK qualification generally taken in a number of subjects over two years and typically studied between the ages of 14 and 16.*

iGCSE – International General Certificate of Secondary Education
*An international equivalent of the UK GCSE qualification. It is typically more examination-based that GCSEs and is viewed by some to be more rigorous. Its use in UK schools is predominantly in independent schools.*

INSET – IN-SErvice Training day
*Staff training days within UK schools.*

MATE – Measure of Acceptance of the Theory of Evolution
*An instrument designed by Rutledge and Warden (1999) to assess evolution acceptance.*

PGCE – Postgraduate Certificate in Education
*A one year, higher education course in the UK which provides teaching training for university graduates. Those studying on a PGCE course are called pre-service or trainee teachers.*
RS – Religious Studies
A GCSE examination course in the UK.

TES – Times Educational Supplement
A weekly publication aimed at UK school teachers. Within this thesis, the abbreviation refers to the TES website (https://www.tes.com/uk/). This is a popular website featuring teaching resources, jobs, and forums.