Chasing Polys: Interdisciplinary Affinity and its Connection to Physics Identity

Tyler Scott
Clemson University, tylerhollie@gmail.com

Follow this and additional works at: https://tigerprints.clemson.edu/all_dissertations
Part of the Physics Commons, and the Science and Mathematics Education Commons

Recommended Citation
https://tigerprints.clemson.edu/all_dissertations/1419

This Dissertation is brought to you for free and open access by the Dissertations at TigerPrints. It has been accepted for inclusion in All Dissertations by an authorized administrator of TigerPrints. For more information, please contact kokeefe@clemson.edu.
Chasing Polys: Interdisciplinary Affinity and its Connection to Physics Identity

A Dissertation
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy
Engineering and Science Education

by
Tyler D. Scott
December 2014

Accepted by:
Dr. Zahra Hazari, Dissertation Advisor
Dr. Geoff Potvin
Dr. Leidy Klotz
Dr. Lisa Benson
Dr. Penelope Vargas
Abstract

This research is based on two motivations that merge by means of the frameworks of interdisciplinary affinity and physics identity. First, a goal of education is to develop interdisciplinary abilities in students’ thinking and work. But an often ignored factor is students interests and beliefs about being interdisciplinary. Thus, this work develops and uses a framework called interdisciplinary affinity. It encompasses students interests in making connections across disciplines and their beliefs about their abilities to make those connections. The second motivation of this research is to better understand how to engage more students with physics. Physics identity describes how a student sees themselves in relation to physics. By understanding how physics identity is developed, researchers and educators can identify factors that increase interest and engagement in physics classrooms. Therefore, physics identity was used in conjunction with interdisciplinary affinity.

Using a mixed methods approach, this research used quantitative data to identify the relationships interdisciplinary affinity has with physics identity and the physics classroom. These connections were explored in more detail using a case study of three students in a high school physics class. Results showed significant and positive relationships between interdisciplinary affinity and physics identity, including the individual interest and recognition components of identity. It also identified characteristics of physics classrooms that had a significant, positive relationship with inter-
disciplinary affinity. The qualitative case study highlighted the importance of student interest to the relationship between interdisciplinary affinity and physics identity. It also identified interest and mastery orientation as key to understanding the link between interdisciplinary affinity and the physics classroom.

These results are a positive sign that by understanding interdisciplinary affinity and physics identity together, researchers and educators can make progress towards development of interdisciplinary affinity and better engagement in the physics classroom. There are several interesting paths for future research that incorporate other important frameworks in education research. These offer even more opportunities for improving education research and practice.
Acknowledgments

First, I would like to thank my wife Hollie for supporting me through several years of graduate school including a couple of years without much direction or end in sight. She worked an often thankless, full-time job and encouraged me when I thought I would not succeed. I am very thankful for her.

I also owe thanks to Drs. Zahra Hazari and Geoff Potvin who helped me transition to the Engineering & Science Education Department and showed me I can still be a physics person without being in a physics department. Both encouraged me to pursue my research interests and have been supportive every step of the way. As mentor and dissertation advisor, Dr. Hazari has worked very hard to guide my work and career and I want to thank her for it.

Thanks is also due to the rest of my committee and the rest of the Engineering & Science Education Department. All the faculty and graduate students have been tremendously supportive and eager to help. The unique combination of disciplinary backgrounds and personalities along with the constant readiness to help out a peer sets a high standard for academic workplaces everywhere.

Of course, this work could not be done without the help of literally thousands of study participants. These college students will probably never know the impact their participation has on education research. Particularly, I want to thank the students and teachers that allowed us into their classrooms and let us watch them and ask
them questions during the case study phase of this research. Each of the high school
teachers we met are making a difference in their communities.

Finally, another necessity for this work was financial support. For that, I
would like to thank the National Science Foundation. The SaGE study was funded
by Grant No. 1161052, while the OPSCI study was funded by Grant No. 1036617.
# Table of Contents

Title Page ................................................................. i
Abstract ................................................................. ii
Acknowledgments ....................................................... iv
List of Tables .......................................................... viii
List of Figures .......................................................... ix

1 Introduction ............................................................ 1
   1.1 Historical Context of Interdisciplinarity ....................... 4
   The Liberal Arts ................................................... 5
   General Education ............................................... 6
   The Humanities ............................................... 7
   1.2 The Modern Movement for Interdisciplinarity ............... 8
   1.3 Interdisciplinarity and Physics ............................. 10

2 Theoretical Frameworks of Interdisciplinarity and Physics Identity 14
   2.1 Interdisciplinarity and Related Terms ....................... 15
   2.2 Interdisciplinary Affinity .................................. 18
   2.3 Physics Identity .......................................... 20

3 Finding the Connection Between Interdisciplinary Affinity and Physics Identity 26
   3.1 Methods: The SaGE survey and data analysis ............. 27
   3.2 Results ................................................... 32
   3.3 Conclusions and New Questions ........................... 41

4 Digging Deeper: The Qualitative Connections ..................... 44
   4.1 Data and Methods ........................................ 45
   4.2 Results ................................................ 51
   4.2.1 Breadth of interdisciplinary affinity ................. 51
   4.2.2 Physics and math differences ........................ 53
List of Tables

3.1 Regression model predicting physics identity (N=2,066). **: $p<0.01$; ****: $p<0.001$; ns: not significant. ...................................................... 34

3.2 Regression model predicting mathematics identity (N=2,066). **: $p<0.01$; ****: $p<0.001$; ns: not significant. ...................................................... 36

3.3 Regression model predicting interdisciplinary affinity (N=2,066). **: $p<0.01$; ****: $p<0.001$; ns: not significant. ...................................................... 39

4.1 Regression model predicting interdisciplinary affinity with STEM mastery orientation included (N=2,066). **: $p<0.01$; ****: $p<0.001$; ns: not significant. ...................................................... 72

5.1 List of interdisciplinary related items included on the OPSCI survey including the dimension of interdisciplinarity each was hypothesized to fit. ................................................................. 79

5.2 Results of exploratory factor analysis of the survey items used in this study to build an interdisciplinary affinity measure. Contrast with hypothesized structure shown in Table 5.1 ...................................................... 82

5.3 Results of exploratory factor analysis of the survey items gauging interests in various academic fields. ................................................................. 85

5.4 Regression model predicting physics identity (N=6,960). **: $p<0.01$; ****: $p<0.001$; ns: not significant. ...................................................... 87

5.5 Regression model predicting physics interest (N=6,960). **: $p<0.01$; ****: $p<0.001$; ns: not significant. ...................................................... 88

5.6 Regression model predicting physics recognition (N=6,960). **: $p<0.01$; ****: $p<0.001$; ns: not significant. ...................................................... 88
List of Figures

1.1 Google Ngram chart illustrating the historical usage of the word “interdisciplinary” (Michel et al., 2011) .................................................. 4

2.1 The model of science identity used by Carlone and Johnson (2007). ...................................................... 22
2.2 The model of physics identity used by Hazari et al. (2010b). ................................................................. 23
2.3 Conception of physics identity as used in this work. Arrows indicate the directions used in SEM by Cribbs et al. (2012) and Potvin and Hazari (2013). .......................................................... 25

3.1 Visualization of research questions 2 & 3. Question 2 relates interdisciplinary affinity to physics identity along with other attitudes and beliefs about science. Question 3 seeks to establish links between the high school physics classroom and physics identity. ............................................. 28
3.2 Map of home zip codes of SaGE study student participants. There is one dot per zip code regardless of the number of participants from each code. ................................................................. 29

4.1 Results from student interviews showing differences in students’ conceptions of math and physics identities in terms of interest and performance/competence (P/C). Schuyler’s identities had a greater interest focus while all three saw physics identity through interest more than math. The strength of physics and math identities are obtained from survey responses and are shown in parentheses. .................................................. 57
4.2 Diagram illustrating the relationship between interdisciplinary affinity and the physics identity framework. ...................................................... 60
4.3 Concept map following Figure 4.2 adding real-life relevant topics in physics class and its relationship to physics interest. ............................................. 63
4.4 Concept map following Figure 4.3 adding the relationships between conceptual understanding, mastery orientation, and interdisciplinary affinity. .......................................................... 67
4.5 Concept map following Figure 4.4 adding the relationships between multi-step problems and individual work and mastery orientation. ... 71
5.1 Histogram of responses on the OPSCI survey to the item “Being well-rounded is important to me.” Strongly disagree = 0, strongly agree = 5.
Chapter 1

Introduction

Instead of studying tomes scholastic,
Ecclesiastic, or monastic,
Off I fly, careering far
In chase of Pollys, prettier far
Than any of their namesakes are, –
The Polymaths and Polyhistors,
Polyglots and all their sisters.

- Thomas Moore

In this section of Thomas Moore’s poem *The Devil Among the Scholars*, the poet describes a student who is distracted from his studies. He mentions three “Polys” that contrast with the “Pollys” drawing the student’s attention. The prefix poly- comes from a Greek root meaning many or much. Perhaps surprising in our disciplinary academic culture, the Greek words from which we derive the English words history and math are virtually synonyms that mean learning. The result is that polyhistor and polymath describe, “A person of great or varied learning,” or an “ac-
The title of this dissertation, *Chasing Polys* is intended to communicate two meanings. First, it is valuable for students to “chase” interdisciplinarity (which is closely related to the idea of being a polymath or polyhistor) both in the betterment of themselves and to better equip themselves for their life’s work. Secondly, physics educators need to “chase” the potential polymaths and polyhistors in their classrooms by helping them include physics in their “great and varied learning.” By doing so, physics as a discipline can become stronger.

Before moving on then, it is important to introduce interdisciplinarity. Interdisciplinarity is used in a broad and a narrow sense. In both cases, it can mean a characteristic of an individual or a framework for research or pedagogy. Chapter 2 will discuss the narrow definitions of interdisciplinarity. But for now, this discussion will focus on interdisciplinarity in a broad sense, that is, combining perspectives, methods, and information from two or more disciplines. Interdisciplinary pedagogy uses this integration of disciplines to help students engage and to present a holistic view of information and learning. An interdisciplinary individual is one who can integrate multiple disciplines and can see information as connected. In most of the literature, the emphasis is on interdisciplinary pedagogy. In some cases, the purpose of interdisciplinary pedagogy is a better education for students. In other cases, the focus is on developing interdisciplinary individuals.

In the first case, many proponents of interdisciplinarity claim that developing interdisciplinary individuals is important for facing the challenges of research in our increasingly specialized though connected world. STEM (Science, Technology, Engineering, and Mathematics) fields are no exception. The NSF has argued that interdisciplinary perspectives are needed for research collaboration (National Science

\[1\]

A polyglot is a person who knows many languages (Oxford English Dictionary, 2014a).
Foundation, 2006). From an engineering perspective (though generalizable), there is also a need for global competitiveness which can be fostered through interdisciplinarity (Vest, 2006). Physics is no exception. The emergence of biophysics as a discipline in its own right illustrates the contribution of interdisciplinary research. Geospace and atmospheric physics fields include researchers collaborating among physics, electrical engineering, aerospace engineering, and chemistry disciplines. These arguments for interdisciplinarity focus on the need to approach problems that would be more difficult - if not impossible - to answer with traditional disciplinary perspectives.

In addition, others have argued interdisciplinary education is a worthy end unto itself. Lattuca et al. (2004) argued that interdisciplinary education is more effective by, a) “engaging students’ prior knowledge and experience,” b) “encouraging effective thinking,” c) “developing multiple perspectives,” d) “motivating students to learn,” and e) “constructing meaning in the classroom.” Proponents argue that breaking down barriers between STEM disciplines can improve learning, conceptual understanding, and application to the real world, especially by avoiding compartmentalization of knowledge (Asghar et al., 2012).

Therefore, interdisciplinarity has become a popular theme in education over the last 40-50 years. The usage of the word “interdisciplinarity” saw its growth during the 1960s and has stayed relatively level since. Google’s Ngram data (see Figure: 1.1) show current usage levels of the word “interdisciplinary” is comparable to levels in the 1970s (Michel et al., 2011). The edited volume Interdisciplinarity and Higher Education, published in 1979, contains essays addressing many of the same issues confronting researchers today (Kockelmanns, 1979a; Hausman, 1979; Swoboda, 1979; Flexner, 1979; Kockelmanns, 1979b). These include questions about the utility of interdisciplinarity, the historical context of the push for interdisciplinarity, and how to define interdisciplinarity and related terms.
Figure 1.1: Google Ngram chart illustrating the historical usage of the word “interdisciplinary” (Michel et al., 2011)

The fact that these questions have occupied education thinkers for over 30 years can be viewed as a glass half-full/empty problem. It can seem puzzling and discouraging that many of these issues have not been resolved. However, it is apparent that there has been some progress in some areas. It is also valuable to recognize that there is something to be learned from the history of the push for interdisciplinarity.

1.1 Historical Context of Interdisciplinarity

A common cliche is that being interdisciplinary is being “well rounded.” This equivalence is not so simple. As will be shown in Chapter 5, being “well rounded” does not always mean interdisciplinarity in students’ minds. It is possible that well-roundedness is a necessary condition for interdisciplinarity, but it is not sufficient.

An important point to clarify in the discussion of interdisciplinarity is the distinction between education and training. Though these terms are usually not distinguished and often used synonymously, they traditionally have communicated
different ideas. Education communicates the idea of making the student a better person. On the other hand, training was the process by which the student accumulated the knowledge required for a job, career, or research.

“To give every one education and to give no one vocational training is impossible, for electricians and surgeons we must have and they must be trained. Our ideal must be to find time for both education and training.” (Lewis, 1972)

I hope to show that interdisciplinarity is relevant to both the education and training aspects of modern schooling.

Interdisciplinarity is sometimes viewed as the outcome or goal of a liberal arts, general education, or humanities curriculum. While the modern idea of interdisciplinarity is somewhat related to these concepts, there are some important differences. The purpose of this section is to briefly outline the history of these ideas to better understand the place of interdisciplinarity in the history of Western education.

The Liberal Arts

The idea of the liberal arts education is best understood in contrast to what were known as the servile or mechanical arts. It closely parallels the difference between education and training. At least as far back as ancient Greece, a liberal education was that which emphasized the inherent value of education as enlightening rather than useful for a trade (Cordasco, 1965, p.8). In the Middle Ages, philosophers and educators described seven liberal arts which were divided into the Quadrivium (arithmetic, geometry, music, and astronomy) and the Trivium (grammar, rhetoric, and dialectic) (Walton, 1993). This organization of subjects was used as far back as Roman and Greek times (Cordasco, 1965; Kockelmans, 1979a). On the other hand,
the servile arts or *artes mechanicae* as they were known in the Middle Ages were the professional skills of builders, craftsmen, and other laborers (Walton, 1993). (This distinction is still seen in modern university organizational structure where despite considerable content overlap, engineering disciplines are usually separated from math and science which were part of the classical *artes liberales*.)

This distinction between education and training is well illustrated by a line in the movie *Dead Poets Society*. In this movie, teacher John Keating says,

“We don’t read and write poetry because it’s cute. We read and write poetry because we are members of the human race, and the human race is filled with passion. Medicine, law, business, engineering, these are noble pursuits and necessary to sustain life. But poetry, beauty, romance, love, these are what we stay alive for.”

Interdisciplinarity is connected to the liberal arts in that the liberal arts are intended to develop in students a holistic view of information and the world around them. Sometimes students taking classes outside their discipline become frustrated because they see no usefulness towards their future careers. Interdisciplinary pedagogy is helpful towards making different courses seem relevant to students and emphasizing the importance of education.

**General Education**

The general education movement is an philosophical descendant of the liberal arts education. The subject matter of the curriculum is different, eliminating and emphasizing certain topics based on the needs of the 20th century (Flexner, 1979). In the inaugural issue of *The Journal of General Education*, editor Earl McGrath outlined the philosophy and goals of the general education movement (McGrath,
1946). Some of these are closely related to interdisciplinarity.

First, general education was, “a reaction against specialism and vocationalism.” This is where general education is firmly rooted in liberal arts education philosophy. With social reforms, industrial revolution, increases in knowledge, and the rapidly changing technology of the 19th and early 20th century, schooling had seen a transformation towards specialization and the forming of disciplines as well as vocationalism (a philosophy that the purpose of school is training) (Swoboda, 1979; Kliebard, 1999).

However, there was more to the general education movement. While rejecting vocationalism, the general education movement did value utility. McGrath and others believed a general education needed to be well connected to real life. While connecting education to real life is not explicitly interdisciplinary, literature and some research including portions of this dissertation links interdisciplinarity to real life connections. But McGrath also unambiguously connects general education to interdisciplinarity by stating that one of its goals is “to integrate the subject matter of related disciplines.” So the general education ideal is connected to interdisciplinarity and perhaps the modern interdisciplinary movement can trace some of its intellectual heritage to the general education movement.

The Humanities

Sometimes, the humanities are considered interdisciplinary in the same way liberal arts or general education are. This is depends on what is meant by “the humanities.” Originally, the humanities were closely tied to the liberal arts. The etymology of the word came from the idea that this was the educational curriculum that was essential to being human (Cordasco, 1965; Kockelmans, 1979a). In this
interpretation, the humanities were essentially indistinguishable from the liberal arts. Some colleges still offer a “Humanities” major which is an interdisciplinary, liberal arts major (The College Board, 2014). However, as a domain of disciplines, the humanities evolved during the Middle Ages to describe only language and literature (Cordasco, 1965, p. 43). With the development of the social sciences, these disciplines came to be considered part of the humanities as well (Kockelmans, 1979a). In this modern sense the humanities are only interdisciplinary in the same way as any other collection of disciplines. They can be taught using interdisciplinary pedagogy or viewed as connected by interdisciplinary individuals. But these connections are no more inherently interdisciplinary than any other collections of academic disciplines.

1.2 The Modern Movement for Interdisciplinarity

Before continuing with a discussion of interdisciplinarity, it would be valuable to clear up two potential misconceptions. First is that an interdisciplinary person is “a jack of all trades and a master of none,” or knows nothing about everything (Kockelmans, 1979b). In fact, interdisciplinarity requires deep understanding in at least one area of knowledge (Borrego and Newswander, 2010). And, though the interdisciplinary person is not an expert at everything, their interdisciplinary knowledge and skills are useful. The interdisciplinarity that results from a general or liberal arts education includes critical thinking skills that are useful even when the individual is not in their realm of expertise. Aristotle described this individual as one who is able to expertly evaluate and analyze all areas of knowledge (Aristotle, 2001).

A second misconception is that interdisciplinarity is the same as a liberal or general education and, therefore, is not relevant to those concerned with training or vocationalism. However, in a list of motivations for interdisciplinarity, Klein and
Newell (1998) cite a general and liberal education followed by professional training. The critical thinking skills that an interdisciplinary general education provides is what transcends the liberal or general paradigm and allows interdisciplinarity to be useful in the vocational curriculum. Another theme that has and will emerge from this discussion of interdisciplinarity is that it is useful in the modern workplace for solving complex problems and because knowledge is rapidly changing and increasing. A catch phrase in the modern job market has been “transferable skills” which interdisciplinarity certainly could help provide (Jeffcote, 1997). Dare (2001) also describes how learner-centered pedagogies (including interdisciplinary courses) can be used in community colleges for vocational training.

Klein (2002) attributes the current significance of interdisciplinarity to four factors: knowledge change, educational reform, problem solving, and critique.

**Knowledge Change:** Knowledge change includes several dimensions, but primarily this is concerned with the increase and specialization of knowledge. With the increase of knowledge, it is no longer possible (if it ever was) for anyone to “know everything” (Kockelmanns, 1979a). This necessarily leads to specialization which gives rise to academic disciplines. But these disciplines change, and interdisciplinarity is required to make progress in research areas which in turn can sometimes lead to new disciplines (e.g. biophysics).

**Educational Reform:** Klein (2002) points out that integrated curricula can be traced back through the 19th century. The classical and medieval traditions of the liberal arts could be considered integrated as well. However, in the modern context, she notes that advocates of integrative curriculum reform argue, “that sophisticated levels of learning cannot be attained by studying subjects separately.”
Also, interdisciplinarity pedagogy can employ more student focused techniques (Lattuca et al., 2004). McGrath (1946) argued that the general education revolt against specialization was also a repudiation of a philosophy of education in which the teacher’s focus is on information instead of students.

**Problem Solving:** The “problem solving” motivation for interdisciplinarity is one of the ways in which modern interdisciplinarity is relevant to vocationalism. In today’s quickly changing workplace, students as future employees need to be ready to face interdisciplinary challenges, work in diverse teams, and think critically.

**Critique:** Klein’s final point is that of interdisciplinarity as a critique. For example, interdisciplinarity might challenge the traditional structures of schools, education, and academic disciplines. Also, thinking about interdisciplinary pedagogy raises the question, “What is the purpose of education?” Finally, some academic fields concerned with critique (such as feminist or ethnic studies) are interdisciplinary.

### 1.3 Interdisciplinarity and Physics

Despite its interdisciplinary connections, physics suffers from a reputation and reality of isolation. High school students describe physics in heteronomous terms, seeing physics as allowing little freedom of expression (Kessels et al., 2006). Analysis of journal citations have found physics at or near the bottom of science disciplines in rankings of cross-disciplinary citations. The National Science Foundation analyzed eight broad fields of scientific and technical articles and calculated how many were cited by articles in other fields. The field of physics and the field of Earth & space
science were tied for the highest rate of self citation at 83% (National Science Board, 1998). Van Leeuwen and Tijssen (2000) used narrower definitions to define disciplines and calculated a cross-disciplinary citation rate for 119 STEM disciplines. Astronomy and astrophysics had the lowest rate of cross-disciplinary citation at 14.3%. The category of general physics and that of atomic, molecular, and chemical physics were both ranked in the bottom 15 disciplines (60% and 59% cross-disciplinary citation rates respectively). Analysis using author affiliation instead of journal categories gives similar results (Ortega and Antell, 2000). The average self-citation rate of physics was higher than both chemistry and biology. The authors also looked at citation rates to physics, chemistry, and biology from a wide range of engineering and science fields. They found physics was cited by authors in other disciplines at lower rates than chemistry or biology.

By opening physics to interdisciplinary connections, teachers might engage students with physics and ignite a fresh interest in physics topics. A few studies have examined connections between physics and the arts and humanities in the classroom. For example, Teixeira et al. (2009) and Garcia et al. (2010) represent several studies which connected physics to history while work by van der Veen (2012) involves art in the science classroom. The Project Physics curriculum, which has existed for decades, integrates physics with the history and philosophy of science (Holton, 2003). Engineering education especially has sought to develop curricula integrating mathematics and the basic sciences. Al-Holou et al. (1999) surveyed several of the integrated curricula in engineering at various institutions. Reported results were generally positive, though some have not found long-term success. While results from these studies often show improved learning gains and/or student attitudes, these results are complicated by confounding variables. For example, most of these studies also included “reformed” environments with high levels of active learning, raising alternative expla-
nations for the observed improvements. However, they show signs of hope that the rigid, unapproachable physics stereotype might be changed through interdisciplinary connections.

In particular, this work focused on physics identity which captures students’ attitudes, feelings, and interests in physics. These factors give insight that focusing on performance factors does not. Also, since physics identity is significantly related to physics career choice (Hazari et al., 2010b), it is important to the physics community to understand this construct in the context of recruitment and retention issues. By learning what factors help develop a physics identity, the physics community can increase the number of physicists and help prevent disillusionment on the part of physics students.

But beyond recruitment and retention, an increase in physics identity among non-physics majors could improve the public perception of physics. For example, by expanding what gets recognized in the physics classroom or by broadening the appeal of physics to students with diverse interests, physics teachers could increase the physics identity of a broader population of students. This would have positive effects on the common perceptions of physics and how individuals engage with physics after leaving the classroom. It could have the effect of decreasing the number of people who have a negative perception of physics. Engaging more students can begin with understanding physics identity. And understanding how interdisciplinarity relates to physics identity could unlock clues to recruiting interdisciplinary physics majors and engaging a broader range of students from both within and outside STEM.

To summarize, this research seeks two significant outcomes. First is a theoretical and research oriented result. This work will establish a framework of interdisciplinary affinity that can describe students attitudes and interest about interdisciplinarity. This framework will establish a new perspective on research in
interdisciplinarity and form a basis for new research. The second outcome is an understanding of the relationship between interdisciplinary affinity and physics identity. Descriptions of this relationship will be established by quantitative data analysis and explorations of causal mechanisms in this relationship by qualitative analysis. The second outcome has relevance to physics education research, but it also has a practical application. These practical results of the research are largely aimed at secondary physics teachers. Since high school is the first, and often last, exposure to physics for most students, it is the vital time frame to influence students’ attitudes towards the subject. Understanding how to engage more and a broader range of students can help physics educators influence the recruitment and retention of students to physics careers and also change for a lifetime the perspectives of students who may never enter a physics classroom again.

The following chapters will investigate the connections between interdisciplinary affinity and physics identity. Chapter 2 will discuss at more depth the different ideas researchers have of interdisciplinarity and define interdisciplinary affinity, which captures students’ interests and ideas about interdisciplinarity. It will also describe the physics identity framework which will be used in the study. Chapter 3 describes the initial quantitative analysis which connects interdisciplinary affinity with physics identity and discovers pedagogical techniques that significantly correlate to a higher interdisciplinary affinity. Chapter 4 takes a deeper look at these connections using interviews with high school physics students. Chapter 5 uses more quantitative data to better define interdisciplinarity and physics identity and confirm the connections between the two. Finally, Chapter 6 will wrap things up and discuss opportunities for future work.
Chapter 2

Theoretical Frameworks of Interdisciplinarity and Physics Identity

As this cartoon illustrates, interdisciplinarity is not always well defined. This problem of definitions existed over 30 years ago (Kockelmans, 1979b) and is still widespread. Lattuca and Knight (2010) stated, “Definitions [of interdisciplinarity]
devised by scholars do not neatly align with one another, nor with the definitions-in-use of practitioners.” This makes it difficult to conduct research and interpret what is meant by terms such as interdisciplinary, crossdisciplinary, multidisciplinary, or transdisciplinary. Though various authors have defined these terms, there is disagreement between them. On the other hand, others argue that splitting hairs over these definitions misses bigger questions. Hansson (1999) argues the emphasis in interdisciplinary research should be on the particular needs of the problems and balancing pros and cons of interdisciplinarity. “The ‘correct’ definition of interdisciplinarity matters far less than the correct appreciation of the true nature of the problem to be solved.”

Regardless, defining terms is vital to a clear understanding of the issues, especially as they relate to individual studies. As Klein (2002) points out, “Different terms reflect different views of the purpose of curriculum, the best use of knowledge, and the place of disciplines.” Therefore, the following section will discuss some definitions and frameworks of interdisciplinarity used in this work and the more well established framework of physics identity.

For this work (following common usage), interdisciplinarity and interdisciplinary are different parts of speech describing the same concepts. Interdisciplinarity is a noun describing the quality of being interdisciplinary.

### 2.1 Interdisciplinarity and Related Terms

The first broadly disseminated attempt to define terms related to interdisciplinarity was by Kockelmanns (1979b). In this work, he defines a broad and narrow interdisciplinarity. The broad sense of interdisciplinarity is defined as “all nondisciplinary endeavors in research, education, or administration.” One of the difficulties with the term interdisciplinary stems from the fact that it is a popular concept. This
leads to the term being used to describe all sorts of situations where two or more disciplines are involved. The broad definition of interdisciplinarity encompasses all of those uses. Kockelmans (1979b) uses interdisciplinary in the narrow sense to describe the particular case of a new discipline formed in the space between disciplines.

Though Kockelmans (1979b) defines several other terms related to interdisciplinarity, he focuses on three in particular: interdisciplinary, crossdisciplinary, and transdisciplinary. His narrow definition of interdisciplinarity focuses on the formation of a new discipline from the integration of two or more disciplines. A good example is bioengineering. As researchers integrated biology with engineering frameworks to solve new research questions, they eventually developed a new discipline. (He uses discipline in the sense of structural organization, usually academic.) In this framework, a crossdisciplinary endeavor differs from one that is interdisciplinary in that it is not concerned with the formation of a new discipline. Both cases require integration of perspectives and methods from two or more disciplines. Both have the goal of tackling a novel problem that requires cooperation between disciplines. However, crossdisciplinary research (in this framework, these terms primarily refer to research) does not result in a generalizable framework that builds a new discipline.

Transdisciplinary work in Kockelmans’ framework is concerned with bigger questions about a unified perspective of knowledge. While interdisciplinarity and crossdisciplinarity are primarily concerned with research, transdisciplinarity includes a strong concern for education. Its primary goal is “systematically pursuing the problem of how the negative side effects of specialization can be overcome so as to make education (and research) more socially relevant.” This concern with education (as opposed to specialization and training) and the attempt to holistically view knowledge is similar to the concerns of the liberal arts and general education.

A more recent and widely cited framework of definitions of interdisciplinarity
is that given by Petrie (1992). He described multidisciplinary work as cases of cooperation by multiple disciplines on a common problem; trans-disciplinary work as the integration of knowledge or theories from multiple disciplines into a new, unified theory (transcending traditional disciplines); and interdisciplinary work as something in between, where “the integration of the work goes beyond the mere concatenation of disciplinary contributions.” Petrie’s multidisciplinarity is roughly analogous to Kockelmans’ crossdisciplinarity, though Petrie makes a point of stating that his idea of multidisciplinarity does not include integration. Likewise, interdisciplinarity has similar meanings in both frameworks, though Petrie does not require it to result in a new discipline. Transdisciplinarity is similar in both frameworks.

Though there are nuanced differences between these frameworks, there is a general pattern that emerges from them and other interdisciplinary literature.

1. General interdisciplinarity includes education, training, and research that involves cooperation between different disciplines. Some authors require integration to be present to call it true interdisciplinarity, but defining proper or adequate integration presents its own challenges.

2. Interdisciplinarity in the narrow sense is usually focused on research. When used in an educational context, the lines between interdisciplinary, multidisciplinary, crossdisciplinary, and transdisciplinary become even less clear.

A useful definition of interdisciplinarity that generally incorporates many of the qualities cited in the literature and includes educational dimensions is that,

“[Interdisciplinarity is] a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession... and draws upon disciplinary perspectives and integrates
their insights through construction of a more comprehensive perspective.” (Klein and Newell, 1998; Lattuca and Knight, 2010).

Interdisciplinarity and High School

Since this work is concerned with high school and first year undergraduates, it is important to understand interdisciplinarity in that context. One of the difficulties with adapting interdisciplinary frameworks to study interdisciplinarity in high school and the first year of college is that most literature focuses on interdisciplinary research. Also, because interdisciplinarity requires disciplinary frameworks, it is often discussed in the context of undergraduate or postgraduate studies. There has been some concern for interdisciplinarity in the K-12 years. Among others, Jacobs (2002); Beane (2002) describe an integrated high school curriculum in which interdisciplinarity can shape a more holistic view of knowledge and education. On the spectrum of education and training (see Chapter 1), high school probably has more of an emphasis on education than college or university which in turn are more education focused than graduate studies. At each step, students specialize their knowledge more than they had before. So when studying interdisciplinarity in high school students, it is important to note that is is less related to utility than professional researchers and even college and university students.

2.2 Interdisciplinary Affinity

This work focused on “interdisciplinary affinity,” defined as a student’s interest and desire to integrate information and perspectives from multiple disciplines as well as self-perceptions of their competence to do so. This perspective departs from prior research by considering the beliefs and interests of students and ignoring
strict requirements that interdisciplinarity include an adequate level of integration or performance. This section includes the reasoning and justification for using this perspective.

First, this study needs to use a definition of interdisciplinarity not constrained to research. Most of the students who participated in this study are not going to have an academic career. Those who will continue in academia are early in that process. Interdisciplinarity to them is primarily in the realm of education. As students continue through their college experiences, they will develop more expertise and begin the process of specialization that will continue in their careers or graduate school.

Second, this definition focuses on affective dimensions of the study’s participants. Work in the field of interdisciplinarity is almost without exception focused on interdisciplinary performance and competence (eg. Field et al., 1994; Boix Mansilla and Dawes Duraising, 2007; Richter and Paretti, 2009; Lattuca et al., 2012). A drawback is that the various definitions of multi-, trans-, and interdisciplinarity make defining successful performance and competence outcomes difficult. If researchers do not all agree on what interdisciplinarity is, how can we effectively assess students’ performance and ability to be interdisciplinary? Also, a performance oriented education can fall short by neglecting the affective domain. As discussed in Chapter 1, it is desirable to develop interdisciplinary students who can think holistically and integrate knowledge and perspectives from multiple disciplines. But forcing students doing a senior physics thesis to work in an interdisciplinary group or on an interdisciplinary project does not guarantee those students will desire or sustain interdisciplinary work in their careers even if they were successful in the course. Affective variables such as interest and self-efficacy are vital prerequisites to sustained performance (Bandura, 1997). An example of this is found in work by Hazari et al. (2010a) who found intrinsically motivated scientists driven by a “learning orientation” were more productive
than their “performance oriented” peers.

2.3 Physics Identity

The physics identity framework used in this work has been developed over several years and been used in many studies. The simplest way to grasp this idea is to think of how people will often describe themselves as a ______ person (physics in this case). However, to capture more depth and variance, this framework includes dimensions of interest in physics topics and recognition by others as a physics person.

The story of this framework of physics identity begins with Gee (2000) who described identity as the “kind of person” one is seen as. This definition acknowledges that identity includes a social dimension. It includes self reflection and recognition by others. Also, this definition can span different scales. A high school student can have a physics identity which primarily is concerned with one academic subject and how they see themselves in relation to it. But that student’s school identity can go beyond physics to include all arenas of high school including other academic subjects, grade level, SES, and extracurricular activities to name a few. Thus, a physics person may also be a “school person” or “smart person.” And it is possible that physics identity would overlap with mathematics or chemistry identities since some of the performance outcomes and social mores are similar. This student could also have an identity outside of school that is related to hobbies or sports. This sports identity might be formed by watching events on tv and/or participation (where athletic and school identities could overlap and inform each other).

Gee (2000) outlines four types perspectives on identity: nature, institution, discourse, and affinity. The first is a way of viewing how natural effects influence identity (e.g. disabilities). The institutional perspective of identity is the interpre-
The formation of identities as assigned by social structures. A student’s physics identity can (and probably is) influenced by receiving a physics award from school authorities. The third perspective emphasizes the role of a more negotiated social recognition. Through interactions with others in a social network, a student can come to be recognized by peers, family, teachers, and others as being a physics person. Finally, the affinity perspective looks at identity as defined through interest and pursuit of shared experiences with an “affinity group.” Participation in a physics club would be an example of affinity identity, but school physics projects or science hobbies would be examples as well. The dimensions of the physics identity construct used in the work are primarily concerned with discourse and affinity identities, though the other perspectives can influence it as well.

Carlone and Johnson (2007) built on the work of Gee (2000) to establish an identity framework for professional scientists. The authors’ model of science identity is shown in Figure 2.1. This was qualitative work based on interviews with scientists, using their own words to build a model of identity. The authors described performance beliefs, competence beliefs, and recognition by others as key components of this scientist identity, taking for granted an interest dimension since the study’s participants were already well advanced in scientific pursuits.

Adapting this work for quantitative research, Hazari et al. (2010b) built survey items based on the four hypothesized components of physics identity (performance, competence, recognition, and interest) and administered the survey in introductory college English classes around the country. (Since a large scale, national survey includes a broad cross section of the population, interest in physics cannot be assumed.) The model used is illustrated in Figure 2.2. This diagram illustrates the four dimensions of physics identity and emphasizes their interactions with each other. Physics identity is shown as part of an overall identity and interacting with other identities.
Tonso’s (1999, 2006) ethnographic studies of a relatively elite U.S. engineering program provided examples of such students. Tonso found that high-status engineering students (i.e., those who receive the greatest recognition) were sometimes the least skilled (i.e., had the lowest competence). In another scenario, we can envision someone who might be very competent in her understanding of science content and may be able to adequately perform scientific practices, but, for one reason or another, may not recognize herself or get recognized by others as a science person. For example, Tonso (1999, 2006) found women in the engineering program she studied who were extremely competent and excellent performers of engineering practices in small group settings, but who were rarely recognized as legitimate engineers by their professors or with potential future employers.

Our science identity model is based on an assumption that one’s gender, racial, and ethnic identities affect one’s science identity, a connection hinted at, but not made explicit, in previous literature. For example, numerous studies have indicated women pursue science for...
the student has. The authors found their physics identity indicator was significantly and positively correlated with interest in physics careers, lending validity to the measure and demonstrating its importance to physics education research, especially as it pertains to recruitment and retention issues. In addition, Hazari et al. (2010b) found no distinction between students’ performance and competence. For subsequent studies using this framework, performance and competence beliefs were combined to form one construct.

As researchers have used this physics identity framework, it has evolved even more. Changes have been primarily on the performance/competence construct. First, Cribbs et al. (2012) used a mathematics identity construct based on survey items analogous to those used in the physics identity framework. The authors used Structural Equation Modeling (SEM) to better understand the interactions of the identity dimensions. They found performance/competence to only have an indirect effect on identity, moderated by interest and recognition. Potvin and Hazari (2013) found an identical structure for physics identity. In fact, an identity construct of only recogni-
tion and interest dimensions was more strongly correlated with physics career choice and accounted for more variance than an identity construct that included performance/competence.

The resulting model is illustrated in Figure 2.3. Performance and competence factors strongly and significantly relate to interest and recognition factors. These in turn represent the best proxy for measuring physics identity with survey instruments. Therefore, this work will use only interest and recognition to represent physics identity.

The next chapter will discuss the first survey and resulting data used to explore interdisciplinary affinity and its connection to physics identity. This survey asked students about their physics and math identities as well as attitudes towards science and high school experiences. A construct representing interdisciplinary affinity was built using two survey items. This construct showed interesting connections to physics and math identities.
Figure 2.3: Conception of physics identity as used in this work. Arrows indicate the directions used in SEM by Cribbs et al. (2012) and Potvin and Hazari (2013).
Chapter 3

Finding the Connection Between Interdisciplinary Affinity and Physics Identity

“Data! Data! Data! I can’t build bricks without clay.”

- Sherlock Holmes

*The Adventure of the Copper Beeches*

Chapter 2 introduced interdisciplinary affinity and physics identity. Interdisciplinary affinity is a new way of thinking about interdisciplinarity, focusing on interests and competence beliefs. It offers a perspective that goes beyond performance in design courses or research. Physics identity is a powerful way to investigate students’ identification with the field of physics. By linking these, two important goals can be accomplished. The first is to provide insight into how educators can improve physics teaching by developing interdisciplinary affinity in their students and engag-
ing a broad range of students. Second, this work provides a new area of research for those studying interdisciplinarity and physics identity.

To better understand the intersection between interdisciplinary affinity and physics identity, this work is guided by the following research questions:

**RQ1.** How can we quantitatively measure students’ interdisciplinary affinity? (Addressed in the methods section)

**RQ2.** How is this measure of interdisciplinary affinity related to physics identity?

**RQ3.** What characteristics of the high school physics classroom are related to interdisciplinary affinity?

A visualization of research questions 2 & 3 is shown in Figure 3.1. Research question 2 examines how interdisciplinary affinity and other student attitudes and beliefs are related to physics identity while question 3 investigates the connections between the high school physics classroom and interdisciplinary affinity.

### 3.1 Methods: The SaGE survey and data analysis

The data used in this analysis come from the Sustainability and Gender in Engineering (SaGE) project (NSF Grant No. 1036617). This project was aimed at understanding how using sustainability topics in high school science classes might help with the engagement of women in science and engineering. As part of this project, a survey was administered in introductory English courses at 50 colleges and universities around the United States. To obtain a nationally representative sample, institutions were categorized by size and type (two or four-year) and randomly selected for recruitment into the study. To obtain a representative sample of students,
Figure 3.1: Visualization of research questions 2 & 3. Question 2 relates interdisciplinary affinity to physics identity along with other attitudes and beliefs about science. Question 3 seeks to establish links between the high school physics classroom and physics identity.

English classes were selected as they would contain both STEM and non-STEM majors. All 50 institutions that agreed to participate did so, giving a sample size of 6,772. Figure 3.2 shows a dot for each zip code reported on the surveys. Though many zip codes had multiple responses, the map illustrates the wide geographic distribution of the study participants and a reasonable match to population distribution.

The survey asked students about their interest and attitudes towards STEM fields; their experience their physics, chemistry, and biology high-school classrooms; their attitudes towards sustainability issues; and their family and demographic information. Physics identity items were included as well as items hypothesized to measure interdisciplinarity. The complete survey can be found in Appendix A. More information about the SaGE study can be found in Godwin and Potvin (2013).

The first step in this study was to establish a way to measure interdisciplinary affinity. The SaGE project emphasized sustainability topics, many of which are interdisciplinary. So the survey included several items hypothesized to measure interdisci-
Two important considerations were made in selecting the items used in the interdisciplinary affinity measure. First was that integration of insights and perspectives is an essential characteristic of interdisciplinarity (Boix Mansilla and Dawes Duraising, 2007; Borrego and Newswander, 2010; Lattuca and Knight, 2010). Second was the emphasis of this study on the affective domain. Therefore, interdisciplinary affinity needed to include both students desires, interests, and beliefs about themselves and the key characteristic of integration. Therefore, the interdisciplinary affinity measure is built from responses to “I hope to gain general knowledge across multiple fields” and “I identify relationships between topics from different courses.” (All the items used for measuring interdisciplinary affinity and physics identity asked for agreement on an anchored, five-point scale from strongly agree to strongly disagree.) These items clearly emphasize integration and the affective domain. These items offer a more easily measurable approach to studying interdisciplinarity than the performance/competence oriented frameworks.

While these survey items used to measure interdisciplinary affinity have rea-
sonable face validity, they were also administered on a survey in an introductory physics class to further establish validity. This survey included the interdisciplinary items used in the SaGE project (again asking for responses on an anchored five point scale) and additionally asked students to give a brief explanation of the reasons behind their responses. The purpose was to establish how students were interpreting these items and generate hypotheses for new survey items that could be used in future work. Results showed students associated the interdisciplinary affinity items with statements about being “well rounded” and using interdisciplinary connections to help them learn. The student responses indicated they interpreted the survey items as asking about interdisciplinarity in ways they were intended. Also, the survey asked students about their interest in taking electives in various academic fields. The responses to each of the academic fields were added to get a score measuring the breadth of the students’ interests. (Higher scores were more likely to consider electives in more subjects.) This score consisted of the following categories: languages (including English), mathematics, physical sciences, fine arts, biological sciences, and social studies. A correlation between this measurement of broad interest and the interdisciplinary affinity measure was found to be both positive and significant ($r = 0.28, p < 0.001, n = 137$). This also lends to the validity of the interdisciplinary affinity items as actually measuring broad interests. These results - in answer to research question 1 - indicated the interdisciplinary affinity survey items were measuring students interest in being interdisciplinary.

To answer the second and third research questions, two linear models were constructed to investigate the relationships (1) between interdisciplinary affinity and physics identity and (2) between physics classroom factors and interdisciplinary affinity. This method allows for testing whether the various factors are related quantitatively, even in the presence of controls and potentially competing factors.
For the reasons discussed in the previous chapter, the physics identity indicator was built from recognition and interest factors. The recognition factor consists of responses to “My parents/relatives/friends see me as a physics person” and “My physics teacher sees me as a physics person.” The interest factor consists of responses to “I am interested in learning more about this subject” and “I enjoy learning about this subject.”

For the third research question, several items probing the students’ experience in the physics classroom were used. These came in several types. Some asked for agreement on an anchored five-point scale. For example, the survey asked about the level of conceptual understanding required in class and how enthusiastic the teacher was about physics. Others were binary for which students answered yes if the statement was true in their experience. For example, several questions asked if certain assessments or activities were part of their physics class. Also, a few questions asked how often they engaged in pedagogical methods on a scale ranging from never to daily. Examples include how often they “spent time doing individual work in class” or “classmates taught each other.”

Data analysis was carried out with R version 2.15.3 (R Core Team, 2013). The code used for these analyses is found in Appendix B. To begin, the sample was culled to include only surveys in which the student indicated attendance in a high school physics class via a reported grade. Using the Amelia II package (Honaker et al., 2011), missing data was imputed to obtain a sample size of 2,066. Two linear models were built using the Zelig package (Kosuke et al., 2008) to address research questions 2 & 3. For the first model, the physics identity indicator was used as the outcome variable with controls of demographics, family variables, and several classroom related items that were thought to be strong, significant predictors of physics identity like those reported by Hazari et al. (2010b). These classroom items were
restricted to environmental factors, not pedagogy, to avoid confusion with the second research question which included classroom pedagogy. The interdisciplinary affinity indicator was used as a predictor along with other “ways of thinking” items that were asked on the SaGE survey. These probed students’ agreement with statements about the nature and value of science (both generally and personally) and perspectives on problem solving. These attitudes and beliefs could potentially complement or compete with interdisciplinary affinity. Therefore they were included to obtain a more complete model of how students’ beliefs relate to their physics identity. The natures of these items are explored further in the results and discussion section.

To accomplish the goal of identifying the physics classroom factors that influence interdisciplinary affinity, a second model was built with interdisciplinary affinity as the outcome variable. Again, demographic and family information were used as controls with predictors being various physics classroom pedagogy and experiences. These classroom experiences and teachers’ pedagogical methods could potentially influence the development of interdisciplinary affinity.

For all linear models, a significance threshold of $p = 0.01$ was used to reduce the chance of Type I error.

### 3.2 Results

The first model predicting physics identity had eight significant, positive predictors. The complete results from the first model are shown in Table 3.1. Race and socio-economic status were included but were not significant. (Parental education was used as a proxy for SES.) Significant controls were being male ($\beta = 0.20, p < 0.001$), physics grades ($\beta = 0.18, p < 0.001$), having a father who is a scientist ($\beta = 0.06, p < 0.01$), family had science related hobbies ($\beta = 0.10, p < 0.001$), and the interest
level of fellow students in the physics classroom ($\beta = 0.27, p < 0.001$). Of the “ways of thinking” predictors, the following were significant: the interdisciplinary affinity indicator ($\beta = 0.09, p < 0.001$), “Learning science will improve my career prospects” ($\beta = 0.10, p < 0.001$), “Science has helped me see opportunities for positive change” ($\beta = 0.21, p < 0.001$), and “The scientific method always leads to correct answers” ($\beta = 0.08, p < 0.001$). The model had an adjusted $R^2$ of 0.39.

As expected, controls such as physics grade, family influence (hobbies and father with STEM career), and gender were significant, positive predictors of physics identity. These links between physics identity and family support and gender were also found by Hazari et al. (2010b). The classroom predictor that was significant was the interest level of classmates. This was hypothesized by Hazari et al. (2010b) to explain their finding that students in physics classes with higher ratios of male students were more likely to develop higher physics identities.

The two predictors, “Learning science will improve my career prospects” and “Science has helped me see opportunities for positive change,” are defined by Godwin et al. (2013) as components of personal science agency beliefs (what one believes that science can do at a personal level). These results indicate that students who perceive science as being useful to them identify with physics more than those who do not. These agency beliefs are related to, but are distinct from, students’ epistemic beliefs. These agency beliefs emphasize students’ beliefs that science can help them accomplish something personally. The final significant predictor in this model is an epistemic belief that the scientific method “always leads to correct answers.” Again, this is not surprising as high school students perceive physics as heteronomous (allowing little freedom of expression) (Kessels et al., 2006). In broader reviews of the nature of science literature, both students and teachers have been found to have absolute beliefs in the truth and certainty of science (Lederman, 1992).
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Est.</th>
<th>Std. Err.</th>
<th>β</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-0.92</td>
<td>0.15</td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>Controls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Race and SES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physics grade</td>
<td>0.48</td>
<td>0.04</td>
<td>0.20</td>
<td>**</td>
</tr>
<tr>
<td>Math scores</td>
<td>0.11</td>
<td>0.02</td>
<td>0.18</td>
<td>***</td>
</tr>
<tr>
<td>Science scores</td>
<td>0.33</td>
<td>0.22</td>
<td>0.20</td>
<td>**</td>
</tr>
<tr>
<td>English scores</td>
<td>-0.14</td>
<td>0.29</td>
<td>-0.02</td>
<td>ns</td>
</tr>
<tr>
<td>Mother is a scientist</td>
<td>-0.28</td>
<td>0.19</td>
<td>-0.04</td>
<td>ns</td>
</tr>
<tr>
<td>Father is a scientist</td>
<td>0.38</td>
<td>0.13</td>
<td>0.06</td>
<td>ns</td>
</tr>
<tr>
<td>Family science hobbies</td>
<td>0.28</td>
<td>0.05</td>
<td>0.10</td>
<td>***</td>
</tr>
<tr>
<td>Interest of fellow students in physics class</td>
<td>0.27</td>
<td>0.02</td>
<td>0.27</td>
<td>***</td>
</tr>
<tr>
<td>&quot;Ways of thinking&quot; predictors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interdisciplinary affinity indicator</td>
<td>0.14</td>
<td>0.03</td>
<td>0.09</td>
<td>***</td>
</tr>
<tr>
<td>&quot;Learning science will improve my career prospects&quot;</td>
<td>0.10</td>
<td>0.02</td>
<td>0.09</td>
<td>***</td>
</tr>
<tr>
<td>&quot;Science has helped me see opportunities for positive change&quot;</td>
<td>0.21</td>
<td>0.03</td>
<td>0.20</td>
<td>***</td>
</tr>
<tr>
<td>&quot;The scientific method always leads to correct answers&quot;</td>
<td>0.08</td>
<td>0.02</td>
<td>0.07</td>
<td>***</td>
</tr>
</tbody>
</table>

Adjusted $R^2 = 0.39$

† A composite of class grades and standardized test scores.

Table 3.1: Regression model predicting physics identity (N=2,066). **: p<0.01; ***: p<0.001; ns: not significant.

* not significant.
The results from the first model also showed the interdisciplinary affinity measure to be a significant, positive predictor of physics identity ($\beta = 0.09$, $p < 0.001$). However, there are two plausible alternative interpretations. One is that students with interdisciplinary affinity are simply better students who enjoy school. To account for this possibility, the model included several measures of academic performance. Despite the presence of academic performance controls, interdisciplinary affinity remained a significant predictor of physics identity. Another interpretation is the possibility that this link only exists because students with interdisciplinary affinity will simply be interested in physics because they are interested in many topics. If this were true, they should be equally likely to have a math identity as they do a physics identity. To test this hypothesis, a math identity proxy was constructed using the same approach as physics identity and similarly validated. A Pearson correlation calculated for math identity and interdisciplinary affinity was significant and positive ($r = 0.16$, $p < 0.001$) although less so than the correlation of physics identity and interdisciplinary affinity ($r = 0.25$, $p < 0.001$). However, a linear regression model was built predicting math identity using the same “ways of thinking” as predictors along with the same or analogous controls as used in the physics identity model. In this model of math identity, interdisciplinary affinity was no longer a significant predictor. The final math identity model is shown in Table 3.2. This table lists several of the significant “ways of thinking predictors” which are somewhat different than what was seen in the physics identity model. With none of these present in the model, interdisciplinary affinity is a significant predictor of math identity. In contrast, interdisciplinary affinity remains a significant predictor in the physics identity model regardless of the inclusion of other “ways of thinking.”

These differences in the connection to interdisciplinary affinity raise interesting questions about the way students with math and physics identities may be different.
Table 3.2: Regression model predicting mathematics identity (N=2,066). **: p<0.01; ***: p<0.001; ns: not significant.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Est.</th>
<th>Std. Err.</th>
<th>β</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-0.19</td>
<td>0.19</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Controls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Race and SES</td>
<td></td>
<td></td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Gender (1 = Female, 2 = Male)</td>
<td>0.19</td>
<td>0.05</td>
<td>0.07</td>
<td>***</td>
</tr>
<tr>
<td>Grade in highest math course taken</td>
<td>0.15</td>
<td>0.02</td>
<td>0.25</td>
<td>***</td>
</tr>
<tr>
<td>Math scores†</td>
<td>2.30</td>
<td>0.29</td>
<td>0.35</td>
<td>***</td>
</tr>
<tr>
<td>Science scores†</td>
<td>-0.29</td>
<td>0.29</td>
<td>-0.03</td>
<td>ns</td>
</tr>
<tr>
<td>English scores†</td>
<td>-1.33</td>
<td>0.26</td>
<td>-0.20</td>
<td>***</td>
</tr>
<tr>
<td>Mother is a scientist</td>
<td>-0.47</td>
<td>0.24</td>
<td>-0.04</td>
<td>ns</td>
</tr>
<tr>
<td>Father is a scientist</td>
<td>-0.11</td>
<td>0.14</td>
<td>-0.02</td>
<td>ns</td>
</tr>
<tr>
<td>Family math hobbies</td>
<td>0.53</td>
<td>0.06</td>
<td>0.18</td>
<td>***</td>
</tr>
<tr>
<td>“Ways of thinking predictors”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“I prefer to focus on details and leave the big picture to others”</td>
<td>0.07</td>
<td>0.02</td>
<td>0.06</td>
<td>**</td>
</tr>
<tr>
<td>“I plan ahead”</td>
<td>0.07</td>
<td>0.03</td>
<td>0.06</td>
<td>***</td>
</tr>
<tr>
<td>“Learning science will improve my career prospects”</td>
<td>0.08</td>
<td>0.03</td>
<td>0.09</td>
<td>**</td>
</tr>
<tr>
<td>“Science is helpful in my everyday life”</td>
<td>0.16</td>
<td>0.04</td>
<td>0.16</td>
<td>***</td>
</tr>
<tr>
<td>“Science has taught me how to take care of my health”</td>
<td>-0.10</td>
<td>0.03</td>
<td>-0.09</td>
<td>***</td>
</tr>
<tr>
<td>“Science and technologies will provide greater opportunities for future generations”</td>
<td>0.12</td>
<td>0.03</td>
<td>0.10</td>
<td>***</td>
</tr>
</tbody>
</table>

Adjusted $R^2 = 0.31$

† A composite of class grades and standardized test scores.
A possible explanation is that many students who see themselves as math people are also very engaged in science. These students see the benefits of science for their career, in their everyday life, and for future generations. When these students are controlled in the model, the interdisciplinary affinity indicator is not significant. In other words, interdisciplinary affinity is related to math identity because a subset of students who see themselves as math people see value in science and have higher interdisciplinary affinity. However, another portion of the population that see themselves as math people do not see the value of science and have no particular affinity with interdisciplinarity.

Also, follow up qualitative research that will be presented in the next chapter indicates that some high school students view math identity in terms of performance and competence goals and view physics identity more in terms of interest. Therefore, interdisciplinary affinity may be more strongly connected to physics identity because students more easily identify physics identity with interests. This complements the identity models of Cribbs et al. (2012) and Potvin and Hazari (2013) which indicate performance and competence beliefs are not sufficient to positively affect identity. Instead, interest is one of the keys to developing identity. Reviews of math epistemology literature confirm that students view math as rules, procedures, practicing, and memorizing (Muis, 2004). Though some research suggests domain specific epistemic beliefs, the differences found between math and physics identities is interesting since studies of epistemology looking at these disciplines group them into the same domain (Paulsen and Wells, 1998; Muis, 2004).

Next, the various physics classroom factors were built into a model with interdisciplinary affinity as the outcome. The results are shown in Table 3.3 and are discussed in more detail below. This model suggests several pedagogical techniques might be related to students’ interdisciplinary affinity. In this model, students’ gen-
der, race, and socioeconomic status were included as controls but were not significant. The only control that was significant was a proxy of English performance consisting of class grades and standardized test scores ($\beta = 0.11, p < 0.01$). Topics relevant to students’ lives was the only pedagogical factor that met the $p < 0.01$ significance threshold. This survey item was reported as an ordered, multi-level factor with “never,” “rarely,” “monthly,” “weekly,” and “daily” as the possible responses. Weekly ($\beta = 0.14, p < 0.001$) and daily ($\beta = 0.17, p < 0.001$) occurrences were significant, positive predictors of interdisciplinary affinity compared to the level of “never.” Two items related to classroom assessments were significant predictors as well. These were questions requiring several steps of calculations ($\beta = 0.10, p < 0.001$) and the level of conceptual understanding required ($\beta = 0.10, p < 0.001$). In this model, the adjusted $R^2$ was 0.06.

It is not surprising that high English scores are related to interdisciplinary affinity. Based on prior work on interdisciplinarity, we would expect students with interdisciplinary affinity to have strong language and communication skills (Borrego and Newswander, 2010). Furthermore, language and communication are the foundation of education. Broad interests and the ability to connect topics are highly dependent on a student’s general ability to understand and process information whether in printed or auditory form.

A common thread in much of the interdisciplinary education literature is that interdisciplinary pedagogy helps students see the real-world relevance of the class material (Petrie, 1992; Chowdhary et al., 2013; Nargund-Joshi and Liu, 2013). The fact that this model indicates that students who see the topics as relevant to their lives also have more interdisciplinary affinity lends support to these ideas. Perhaps if the physics teacher effectively communicates the relevance of the subject, interdisciplinary students are more likely to be engaged, and other physics students are able to expand
Table 3.3: Regression model predicting interdisciplinary affinity (N=2,066). **: p<0.01; ***: p<0.001; ns: not significant.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Est.</th>
<th>Std. Err.</th>
<th>β</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1.93</td>
<td>0.13</td>
<td></td>
<td>***</td>
</tr>
<tr>
<td>Controls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Race, gender, and SES</td>
<td></td>
<td>ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Math scores†</td>
<td>-0.02</td>
<td>0.15</td>
<td>0.004</td>
<td>ns</td>
</tr>
<tr>
<td>Science scores†</td>
<td>0.11</td>
<td>0.18</td>
<td>0.02</td>
<td>ns</td>
</tr>
<tr>
<td>English scores†</td>
<td>0.44</td>
<td>0.15</td>
<td>0.11</td>
<td>**</td>
</tr>
<tr>
<td>Physics classroom factors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topics were relevant to their life‡</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“Rarely”</td>
<td>0.13</td>
<td>0.07</td>
<td>0.06</td>
<td>ns</td>
</tr>
<tr>
<td>“Monthly”</td>
<td>0.14</td>
<td>0.07</td>
<td>0.07</td>
<td>ns</td>
</tr>
<tr>
<td>“Weekly”</td>
<td>0.25</td>
<td>0.07</td>
<td>0.14</td>
<td>***</td>
</tr>
<tr>
<td>“Daily”</td>
<td>0.30</td>
<td>0.07</td>
<td>0.17</td>
<td>***</td>
</tr>
<tr>
<td>Level of conceptual understanding required</td>
<td>0.08</td>
<td>0.02</td>
<td>0.10</td>
<td>***</td>
</tr>
<tr>
<td>Questions required several steps of calculations</td>
<td>0.19</td>
<td>0.04</td>
<td>0.10</td>
<td>***</td>
</tr>
</tbody>
</table>

Adjusted $R^2 = 0.06$

† A composite of class grades and standardized test scores.
‡ Reference level is “never.”
their thinking to make connections beyond their typical ways of thinking.

Another significant predictor in this model is requiring conceptual understanding. This is another common theme in the literature linking conceptual understanding and interdisciplinary courses (Petrie, 1992; Newell, 1994). And conceptual understanding is sometimes cited as a benefit or characteristic of interdisciplinary education (Lattuca et al., 2004; Garcia et al., 2010). Newell (1994) attributed this to critical thinking skills which are also emphasized by Boix Mansilla and Dawes Duraising (2007) and Borrego and Newswander (2010). Both of these could be at work engaging less interested students in the physics classroom. But the results of the present study are somewhat limited in this respect in that it is not clear what exactly is meant when students report a requirement of conceptual understanding. If it means less of an emphasis on mathematical formalisms, it is easy to see how that might engage a wider population of students. The student with more interest in the humanities can feel like physics is more approachable to them.

Real-world relevance of topics and conceptual understanding go hand-in-hand in literature about interdisciplinary pedagogy. Garcia et al. (2010) studied a physics class emphasizing the historical context of physics content, emphasizing conceptual development through time at the expense of formulae and memorization. They reported the class had more emphasis on “sense making” and that “students were able to draw a better connection between physical concepts and the real world.” The effects were strongest on students from outside STEM. By presenting content in ways that emphasized real-world relevance, conceptual understanding, and the intersections of physics with the humanities, non-STEM students became more engaged with physics. van der Veen (2012) used art in a physics class to engage non-majors with physics topics and expand horizons of physics majors. And in a study of pre-college urban students, Elmesky (2005) found using the media of film and music increased agency
and interest in science. These examples show how making interdisciplinary connections helps make connections to their personal interests and focuses on conceptual understanding. This helps students engage with the class content.

A less expected result is that doing problems requiring several steps of calculations is positively and significantly related with interdisciplinary affinity. Students who reported doing multi-step problems in their high school physics class were more likely to have higher interdisciplinary affinity. Perhaps, a well-written problem with several steps, requires a student to exercise their ability to synthesize information and apply connections between different concepts to solve the problem. Since integration was noted as being the key to interdisciplinarity (Boix Mansilla and Dawes Duraising, 2007; Borrego and Newswander, 2010; Lattuca and Knight, 2010), perhaps teachers should work to present students with challenging, multi-step problems that engage students with interdisciplinary affinity who enjoy integration while helping other students develop skills for integrating information from multiple sources.

### 3.3 Conclusions and New Questions

Connections between physics, math, and other sciences are easy to see, and intersections of physics with the arts, humanities, and every-day life are found in magazines such as *Physics Today* (e.g. Rosenberg, 2005; Carr Everbach, 2007; Parker, 2011; Lokki, 2014). Communicating this interdisciplinary nature, and particular cases of interdisciplinary connections, to students seems difficult in a culture of memorized procedures and academic performance. Developing interdisciplinary physicists (and students in general) depends on developing interdisciplinary skills in physics students and finding ways to engage interdisciplinary students with physics topics. This research gives reason for optimism. Data show interdisciplinary affinity is significantly
correlated with physics identity. Also, there are several tools that the physics teacher can employ that may help students develop interdisciplinary affinity.

While results based on cross-sectional data cannot establish causal relationships, they do provide interesting correlational results. First characteristics of interdisciplinary affinity are significantly related to positive physics identity. Also, there is an intriguing contrast with mathematics identity where interdisciplinary affinity is no longer a significant predictor when ideas about the value of science are considered. Future work on this question should focus on how students might think of physics and math identities in different ways, how math and physics are taught differently, and different epistemic beliefs between the subjects. Since interdisciplinary affinity includes an interest dimension, the interest component of identity is a key area of common ground. It is likely that if a student’s physics identity is based primarily on interest, a link to interdisciplinary affinity would be more likely. This will be explored further in the next chapter.

Several physics classroom factors were found to be significantly and positively related to interdisciplinary affinity. These pointed to classrooms that focus on real-life relevance, synthesis, and conceptual understanding. This work lends support to claims that conceptual understanding and real-life relevance are linked to interdisciplinarity.

Finally, though beyond the scope of the research questions, data show that teacher quality (most significantly, enthusiasm for physics) and a mastery orientation were significantly related to interdisciplinarity. These links provide more interesting questions for future research.

Future work should also focus on examining the causal links between the various factors in these two models. What are the reasons behind the link between interdisciplinary affinity and physics identity? And why is there a contrast between
physics and math identities? How might the interest dimensions of identity connect to interdisciplinary interests? Also, how specifically do classroom experiences link to interdisciplinary affinity? What do particular pedagogical techniques do for the development of interdisciplinary affinity? What does a good multi-step problem look like? Can simply doing multi-step problems develop interdisciplinary affinity or is it that students with interdisciplinary affinity find the integration process appealing?

Finally, future work should focus on developing better models of interdisciplinary affinity. The interdisciplinary affinity indicator used in this chapter was constructed of only two items that cover the most obvious characteristics of interdisciplinarity: broad interests and interdisciplinary performance/competence beliefs. There are few systematic definitions of interdisciplinarity, and none emphasizing affective dimensions. By developing a better and more complete framework of interdisciplinary affinity, future research in this area can capture more nuance and provide more opportunities for research and practical application in the classroom.

The next chapter will build on the results and questions presented here. Qualitative case studies of three students in a high school physics class provided some insight towards answering the questions raised above by better understanding the links between interdisciplinary affinity and physics identity. Chapter 5 will return to the issue of better understanding the construct of interdisciplinary affinity.
Chapter 4

Digging Deeper: The Qualitative Connections

“A human being is an immense abyss, but you, Lord, keep count even of his hairs, and not one of them is lost in you; yet even his hairs are easier to number than the affections and movements of his heart.”

- Augustine of Hippo

Confessions (IV,14,22)

Chapter 3 demonstrated the link between interdisciplinary affinity and physics identity in surveys of freshman college and university students. It raised several questions about why that link exists and why it may be different in math. It also found a few characteristics of high school physics class that are positively related to interdisciplinary affinity.

The purpose of this chapter is to more deeply investigate these relationships. The quantitative results show correlational relationships, but do not explain how
or why they exist. To investigate these questions, qualitative data are necessary. Through interviews with students and observations of high school physics classes, this chapter answers the following questions:

**RQ1.** Why might interdisciplinary affinity be more strongly linked to physics identity than to math identity?

**RQ2.** What explains the links between certain characteristics of the high school physics classroom and interdisciplinary affinity?

### 4.1 Data and Methods

This chapter builds on the previous work that quantitatively investigated connections between interdisciplinary affinity and physics identity and found characteristics of high school physics classes that were connected to interdisciplinary affinity. The qualitative data analyzed in this chapter was also collected as part of the SaGE project. The first part of SaGE was the survey given to students in introductory English courses at 50 colleges and universities around the United States. As already noted, more information about this survey and some of the results are found in Godwin and Potvin (2013); Godwin et al. (2013) and Chapter 3.

The current chapter emerged from the second part of the SaGE study. The survey asked students for the names of their high school science teachers. From this data, the research group identified several exemplary teachers who taught sustainability related topics and employed pedagogical tools of interest. One of these was that that topics were relevant to students’ lives which was one of the important factors that emerged from Chapter 3. Two of these teachers and their respective school administrations agreed to allow researchers to observe their classrooms and interview
them and their students. The data for this work comes from one of those two schools.

The school selected for this work is located in the Western United States and is an average sized school (enrollment is less than 1,000 students). Three graduate student researchers visited this school for one week in the spring of 2013. The teacher selected is a 20+ year veteran of high school chemistry and physical science teaching. During the semester of this site visit, he taught general chemistry, general physics, AP chemistry, and IB physics. The researchers recorded and observed physics and chemistry classes. Data for each class includes video recordings from the front and back of the classroom, field notes from each of the three researchers, and any handouts or assignments that were passed out to the students.

Also as part of the data collection, several students were selected for interviews based on their responses to a survey adapted from the original SaGE survey. The three researchers each had different research questions, so students were selected from all the classes and were chosen primarily for their responses to items pertaining to identity, interdisciplinarity, career interests, and views on sustainability. Also, students’ behavior in class (such as evidence of engagement and their questions and comments) was considered. Three students from the general physics class were chosen for analysis because this work focuses on physics classroom experiences and physics identity (in relation to interdisciplinarity).

During the week-long site visit, the physics class was working on a Rube Goldberg project. Two full days were dedicated to group work on the project as well as portions of the other two days. (This school had a four day school week with class periods lengthened by the appropriate amount to fit in the required hours.) Lecture portions of the remaining two days focused on electrical circuits. The students worked in groups of three or four with each group building a part that would later be assembled with the parts from the rest of the class to create a Rube Goldberg machine.
While not interdisciplinary *per se*, the project included characteristics of interdisciplinarity such as synthesizing various concepts so all the parts worked together.

The three students interviewed during the site visit were in the same class and were all interested in STEM related careers. Therefore, differences in their identities and interdisciplinarity can be evaluated without significant variability due to those confounding variables. During the visit each was interviewed for approximately 20-30 minutes and their contact information was collected for follow-up. During the spring of 2014, the students were contacted for follow-up interviews. Unfortunately, one of the three students did not respond to requests for an interview. So the follow-up data only includes two of the originally interviewed students. Details of the three physics students chosen are given below.

**Schuyler**

Schuyler is a Caucasian male and was a junior at the time of our visit who was interested in a career in either psychiatry or engineering (specifically aerospace or mechanical). He displayed leadership and savvy during the group projects the class was engaged in during the week. During interviews, he expressed the broadest interdisciplinary affinity of the three cases.

In the observations of both the teacher and the researchers, Schuyler was a “leader.” One of the researchers first noticed Schuyler and marked him for an interview because of his ability to explain physics concepts to his group and suggest methods and improvements for the design. His personality was not conspicuously what would be recognized as a leader. However, his ability in physics and his confidence in his ability marked him as the leader in his group. The teacher described Schuyler as, “equally competent in almost any area of physics concepts or applications.”

---

1All names used in this study are pseudonyms.
also active in extracurricular activities including theater and choir.

One year later, when tracked down for a follow-up interview, Schuyler’s career plans had changed. He was then finishing his final year of high school and had decided to major in Fisheries Biology at a university in a neighboring state. When asked about his prior interests, he said his interest in psychiatry had waned slightly after taking a psychology class. His interest in engineering was still strong, but the choice of Fisheries Biology had been due to learning about the field as a career option. He learned of the career from a family friend and decided it fit his interests.

Adlai

Adlai is an Hispanic male and at the time of our visit was a senior planning on attending a small, nationally recognized engineering school and majoring in electrical engineering. He was a student in both the physics and AP chemistry classes observed during the site visit. He also was a teacher’s assistant for the physics teacher. Adlai was the most traditionally academically oriented of the three. During one of the days in which the teacher lectured on electrical circuits, he was the only one to open and use his textbook during the lecture. In addition, he would occasionally point out something in the book to his neighbor. For the Rube Goldberg project, he was busy calculating and solving problems that were turned in to be graded while the others in his group focused on design and measurements.

At the time of the follow-up interview, Adlai was at the same engineering school he planned on attending in high school. He was majoring in electrical engineering as planned. He had read an article about the engineering majors going to medical school and had begun entertaining thoughts of doing that, though this was not a decision he had made yet.

Adlai showed characteristics of interdisciplinarity. However, these were nar-
rower than what Schuyler displayed. Adlai made connections between classes and thought making connections was good for him. But these were generally in the context of his schoolwork and only within STEM disciplines.

Charles

Charles was a senior with Native American heritage who had enlisted in the Air Force to work on radios and electronics. He hoped to have the military pay for his college education and continue working in the electronics field. Charles was very engaged during the week of the site visit. The two lectures during the observation week covered electrical circuits. This topic was high among Charles’ interests. Therefore he was very attentive and took notes during the lecture. He usually had answers to the teacher’s questions. He was also heavily engaged in his group’s Rube Goldberg machine project. He worked with the electrical components and did much of the “hands on” work of building the apparatus. In the words of his teacher,

[Charles] is especially good at the practical application part of physics. He could build and wire and design things with the physics principles embedded… [he] was not only the idea man, but also the one who put most of his group’s project together and even designed a couple of components that would accomplish multiple goals simultaneously.

In contrast to both Adlai and Schuyler, he did not do as well on homework and exam assessments.

Unfortunately, he did not respond to requests for a follow-up interview. Based on posts found on social network sites, it is clear that he has continued with his Air Force career.
All three students were interviewed during the site visit with a semi-structured interview protocol. The outline of this interview protocol is given in Appendix C. During these interviews, the students were asked about their physics, math, and chemistry identities, ideas of what those identities mean, characteristics of interdisciplinary affinity, career interests, opinions about their classes and teacher, and ideas related to sustainability.

For the follow-up interviews the following year, only Schuyler and Adlai responded to requests for interviews. Both were interviewed using the semi-structured interview protocol outlined in Appendix D. This interview again asked them about their career interests and probed deeper into their ideas about their physics and math identities, interdisciplinary affinity, and characteristics of their high school physics class. The questions asked were informed by the quantitative data so the comparison and contrast between math and physics identities was especially important. Also based on the quantitative data, the interview protocol asked about the specific physics classroom characteristics that were discussed in Chapter 3 as significant predictors of interdisciplinary affinity. Finally, the protocol included some other items that were close to being statistically significant in the quantitative data ($p < 0.05$ where the cutoff was $p < 0.01$) and might be of interest. The physics classroom characteristics included: (1) topics relevant to their life, (2) level of conceptual understanding required, (3) questions required several steps of calculations, (4) spending time doing individual work in class.

Both sets of interviews were analyzed using directed content analysis (Hsieh and Shannon, 2005). A priori codes represented established ideas from the physics identity framework (Hazari et al., 2010b; Potvin and Hazari, 2013) and from the quantitative results from Chapter 3. Additional themes were allowed to emerge during coding which helped explain both the quantitative and qualitative data.
4.2 Results

4.2.1 Breadth of interdisciplinary affinity

All three students in this study made connections between their classes and thought it was important to make these connections. However, there was a striking difference in the breadth of these connections and how they were framed.

Schuyler demonstrated the broadest interdisciplinary affinity. He valued connections between physics and

**Biology:** “...Maybe about the body or the brain or how something works, I can compare that to how something works in what I’ve learned in physics.”

**Music:** “There is a lot of different things that we were learning about sound and how sound is created that we’ve kind of learned in choir and it’s like oh, hey, that’s kind of like when we do this in choir, um, I feel like [science and the arts are] interconnected and not different.”

**Math:** “Probably one of the main things that I thought was really cool was when we were learning about the unit circle and the trigonometric [sic] functions and the ratios...It helped me understand when we were studying waves in physics and when we were studying the trigonometric functions in math and how they, how they kind of work together. And I thought that that was really cool that you could go to two different classes and bring what you learned together into one main idea.”

**History:** “I’ve learned about stuff in history and stuff in science and [the physics teacher] will talk about a scientist and he’ll talk about what kind of time period it’s in and it helps me give background to what kind of conditions the scientist
was working and I mean, why did he try that? Why was he trying to solve that problem?”

Adlai and Charles also mentioned interdisciplinary connections, but these were narrower. When asked about connections between classes, Adlai responded, “...math and my two science classes. They’re always hand-in-hand because we’re always doing like math calculations in science.” While Adlai did mention connections between STEM and non-STEM classes, they were narrower in an important way. These connections were articulated in the context of utility and not interest. They were a way for him to succeed in his classes or his career, not because they satisfied a curiosity or interest like they did for Schuyler. Adlai mentioned two interdisciplinary connections between STEM and other fields:

**Business:** “Well, I guess you have to have some sort of business front in order for engineering to, to be publicized to people. You need like business, um, in it somehow to make like deals and stuff. You know, because you also, it’s like engineering is something you kind of want to sell as well, so I mean, I guess, that’s sort of related there.”

**English:** “English, you definitely need that. It helps like expand the vocabulary and everything, you know. I think English is important just to incorporate that as well. And I mean, I think those [English, math, and science] kind of go all together.”

Charles made similar intra-STEM connections, but nothing else. The only time Charles mentioned a connection between classes, it was within the sciences. “We’d be learning one thing in like our science and then I’d be in environmental science and they’d be kind of talking about the same subject and I’d be like oh, yeah,
I learned this in my last class last period.” When asked specifically about STEM and non-STEM classes, he said he did not see those connections.

The three students interviewed showed a range of interdisciplinary affinity from Charles (only limited connections between STEM courses) to Adlai (connections outside of STEM for purposes of academic and career success) to Schuyler (broad connections to satisfy curiosity and interests). The differences between Schuyler and Adlai in particular point to the differences in purpose of interdisciplinarity. As discussed in Chapter 1, arguments for interdisciplinarity include arguments for holistic and utilitarian interdisciplinarity. This qualitative data suggests Schuyler’s interdisciplinary affinity is closer to the former while Adlai’s the latter.

4.2.2 Physics and math differences

As discussed in the Chapter 3, the link between interdisciplinary affinity and math identity was quantitatively found to be weaker than that between interdisciplinary affinity and physics identity. One of the goals of the qualitative study was to investigate the reason for this difference. To answer this question, it was necessary to understand how the students conceptualized physics and math identity. Therefore, each interview (both during the school visit and the follow-up interviews) included questions about the individual’s physics and math identities, their view of what those identities mean, and whether anyone can have a physics or math identity.

Also, since the students exhibit different characteristics and degrees of interdisciplinary affinity, comparisons among them may offer insights as to how interdisciplinary affinity and identity might be linked. Schuyler had the broadest interdisciplinary affinity of the three students and mentioned connecting class content to things outside of class. He described physics identity exclusively in terms of interest. This
contrasts with his descriptions of math identity which is a mixture of both interest and performance/competence. During the site visit interviews, when asked if anyone could be a physics person he said,

“I think anybody could [be a physics person], but I really think you have to have an interest and a good attitude towards it to, um, be good at it. Because if you don’t care you’re not going to try.”

Schuyler’s description of having a math identity included both interest and performance/competence. He said, “A math person is able to understand the concepts, easily be able to explain it to other people.” He described himself as a math person, but said he had not always been that way. His math identity increased in the seventh grade when, “I got more interest in it. Plus, I had a really good teacher in the seventh grade that got me excited about math and so I tried harder.” It was clear from his description that it was not until he had a teacher who helped him develop an interest in math that his math identity increased.

Adlai had high physics and math identities (as measured in the survey and related in interviews), but both were more oriented towards his performance/competence than they were for Schuyler. During the site visit interviews, when asked about what a physics person is, he focused on tasks; “I guess to work with all the physics-related topics like the energy and motion and all that.” But he did recognize the importance of interest to a physics identity because he thought some people cannot be a physics person because, “there’s certain people that wouldn’t enjoy [physics].” But for math, he never mentioned interest. He said being a math person means, “being pretty good at working with numbers, ah, processing things like that, like analytically, you know, all that. Um, being able to just, I guess, think of things more logically. I don’t think anybody could [be a math person]. It just kind of seems like
you kind of have to try harder if you’re not in that mentality already and if you’re like a math person it just seems to come to you.”

Charles likewise used a mixture of interest and performance when describing physics identity. He had an internal conflict about being a physics person because he was interested in physics, but he struggled academically with the math required. “[Physics] interests me, but again the math is dragging me back, pulling me back. Like I really enjoy the class, I like what we do in there. I think what we’re learning is pretty cool but like the math is always just holding me back.” Like Adlai, he never mentioned interest in the context of math identity. When asked what would need to happen to become a math person, he said, “I probably would just have to study and learn, spend time learning more instead of being out with my friends.”

The follow-up interviews with Adlai and Schuyler were consistent with these results. Adlai was perhaps even more performance/competence oriented than before. He only mentioned the importance of interest in passing and in doing so clearly showed the difference in his conception of math and physics identities.

“I feel like not anybody can be a physics person either. But it might be a little bit more open than it is . . . to be . . . a math person because it is well structured, but it still has more like ability to open up to new things. Like, it’s not necessarily a set of rules that you follow always. But I feel like it could interest more people in that way.”

In fact, Adlai’s conception of math identity being linked to performance and competence had led him to think of himself as less of a math person since going to college. He still concluded that he was a math person, but the challenging classes had led to some questioning.

Q: “So, do you still see yourself as a math person?”
Adlai: “Um, I’d like to say so, but this school has kind of changed the way I look at it. (laughing)”

Q: “Okay. How is that?”

Adlai: “Well, it’s definitely a little tougher now. I mean, they don’t give us easy math courses, but I guess that’s a good thing because it helps us learn... So I mean, yeah, it is more difficult now, but I still think I’m somewhat math oriented.”

As before, Schuyler never mentioned performance or competence when asked about physics identity.

“I think what it means to be a physics person is someone who enjoys it, someone who is intrigued and interested and goes after it kind of and is engaged and they think about it. They don’t just go to class and then leave and not thinking [sic] about it or use it [emphasis added].”

He also sees math identity in terms of interest.

“I do think anyone can be a math person. Um, although I do think some people struggle a little more with math than, than other, and I think that you can still be a math person even if you struggle just because you want to be and that’s something here you’re interest in and intrigues you and that’s what you want to do. Because I have some friends who aren’t necessarily very good at math but they love the math class and they like figuring it out and they’re really interested in it.

In sum, when asked about physics identity, Adlai and Charles both used words and phrases associated with performance/competence and interest dimensions of identity, whereas Schuyler only talked about interest. On a hypothetical spectrum of conceptualizing physics identity in terms of performance/competence to interest, Adlai
Figure 4.1: Results from student interviews showing differences in students’ conceptions of math and physics identities in terms of interest and performance/competence (P/C). Schuyler’s identities had a greater interest focus while all three saw physics identity through interest more than math. The strength of physics and math identities are obtained from survey responses and are shown in parentheses.

<table>
<thead>
<tr>
<th></th>
<th>Physics Identity</th>
<th>Math Identity</th>
<th>Interdisciplinary Affinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schuyler</td>
<td>Interest only (Med-High)</td>
<td>P/C &amp; Interest (High)</td>
<td></td>
</tr>
<tr>
<td>Adlai</td>
<td>P/C &amp; interest (Med)</td>
<td>P/C only (Med)</td>
<td></td>
</tr>
<tr>
<td>Charles</td>
<td>P/C &amp; interest (High)</td>
<td>P/C only (Low)</td>
<td></td>
</tr>
</tbody>
</table>

and Charles would be in the middle while Schuyler would be firmly on the interest side. All three students’ positions on the spectrum shifted when asked about mathematics identity. Charles and Adlai only used performance/competence words and phrases when asked about math identity while Schuyler referred to both performance/competence and interest. Though all were positioned further away from interest, Schuyler was still nearer the interest side than both Adlai and Charles. See Figure 4.1 for a visual representation of these results. For Schuyler, identity had a larger interest component than for the others. And, for all three students, physics identity had a larger interest component than did math identity. The strength of their physics and math identities was obtained from their survey responses and is included in parentheses for reference.

Also, Schuyler’s views of identity were that it was something that could be ob-
tained with the right attitude and work. But Adlai thought that there would be some people who simply could not be a physics or math person. This difference in views is similar to self-theories about intelligence (Dweck and Molden, 2005). Self-theories of intelligence have two categories. The incremental view holds that intelligence can be increased by effort and study. It believes that if a student struggles in an academic subject, they can work hard to succeed in that field. On the other hand, entity views of intelligence hold that ability is innate. A student with entity views sees academic success through inherent talent, not through effort. While identity is not intelligence, research in this area can inform interpretation of this data. Dweck and Molden (2005) report that students with entity views of intelligence lose interest and quickly become discouraged when facing difficult tasks or negative feedback. But students with an incremental view accept challenges and use them as learning tools. Both Schuyler and Adlai saw math identity as more performance dependent than physics identity. And coupled to this idea in both interviews was that math identity was less attainable for students. It is likely that students with an incremental style view of identity will thrive in multiple academic areas, leading to a greater interdisciplinary affinity.

These views on identity might explain the reason for interdisciplinary affinity links to physics and math identities being significant and not significant respectively in the quantitative data. If the engagement of interests offers a greater chance for interdisciplinary students to develop higher identity, the fact that these students view math identity as less interest oriented than they see physics identity means there is less chance for interdisciplinary students to develop positive math identities. Even Schuyler, though seeing math identity partly through an interest lens, saw math identity as a performance and competence construct more than he saw physics identity.

This is most clearly seen in the story of Schuyler’s development of a math
identity. Though briefly outlined above, it is worth looking at this transformation in more detail. During the site visit interview, Schuyler related the transformation that took place.

“When I was younger, I didn’t really consider myself a math person because I didn’t really work very hard at it and I didn’t really care that much. And, I guess I just started caring and then I felt like I was getting better at it, I was able to understand. I think it was really I got more interest in it now that I’m thinking about it. Plus, I had a really good teacher in seventh grade that got me excited about math and so I tried harder.” “I remember [the 7th grade math teacher] had like these geometric shapes that she would pull out and show us, um, she would relate it to real life. I guess that’s one thing with me is if you can relate anything to real life or daily life, that interests me.”

During the follow-up interview, when asked again about this change in identity, he said,

I guess the biggest thing for me is when math started becoming real in real life and it was an everyday thing, um, instead of—because in math I always hated the problems that didn’t give a reason for it. I was that weird kid that liked the story problems even though they were harder because I could connect and relate the math with the real world. And if I can’t really connect it, I really don’t see any point in learning it or enjoying it because then it exists only for self.”

This story illustrates the importance of interest (for Schuyler, real-life relevance) for development of identity. These results indicate that interdisciplinary students who have broad interest might be more likely to develop a positive identity if
they see identity as constructed through interests. Connecting physics course content to students’ conceptions of real life relevance is important to fostering physics interest and identity as well as interdisciplinary interests. Interdisciplinary students with broader interests may be more likely to connect to physics than math because they see connections to these interests. These relationships are illustrated in Figure 4.2. This concept map shows the vital connection between interdisciplinary affinity and physics interest. Based on the qualitative data analyzed in this chapter and the framework of physics identity used in this work (Potvin and Hazari, 2013), this relationship holds the key to connecting interdisciplinary affinity to physics identity.

4.2.3 Interdisciplinary affinity and the physics classroom

The follow up interviews with Schuyler and Adlai also provide insight into the connections between interdisciplinary affinity and the high school physics classroom.
In each interview Schuyler and Adlai were each asked specifically about their physics class and about the characteristics found to link to interdisciplinary affinity in the prior quantitative work.

**Topics relevant to their life**

As shown in the previous chapter, the frequency of topics in high school physics that were relevant to students’ lives was a significant, positive predictor of interdisciplinary affinity. Elmesky (2005), Garcia et al. (2010), and van der Veen (2012) saw positive results in interdisciplinary physics courses from making connections to real life. Increases in science interests were also seen in high school science classes when students were prompted to connect the class content to their lives (Hulleman and Harackiewicz, 2009). These connections can differ just as Schuyler and Adlai’s interdisciplinary affinity does. Real life connections can be made to phenomena around the student that excite curiosity (like Schuyler) or to the personal goals and careers the student has (like Adlai). The goal in this section is too see how Schuyler and Adlai describe connections between their physics course and their lives and how that relates to their interdisciplinary affinity.

When asked about seeing physics topics as relevant to their lives, there was both a quantity and quality difference between Schuyler and Adlai. One of the fundamental differences in how Schuyler and Adlai talked about class topics (and STEM in general) being relevant to their life is that Adlai focused on his college coursework and future career while Schuyler talked about life outside of academics. Adlai spoke only generally about the value of physics in teaching critical thinking skills.

“I think it definitely is [important for people to take a physics class] because, I mean, it might not be something that relates necessarily to what
you’re doing exactly, but it definitely helps . . . like practice problem solving skills and that’s something that I definitely want to get better at.”

Schuyler, on the other hand, constantly cited concrete examples from his life where math and physics were relevant to his life.

“I was that weird kid that liked the story problems even though they were harder because I could connect and relate the math with the real world.”

“I wanted to build a table out of a log, so the top was like a pine log top, and I needed to know the diameter of the log to put on the size of the table. So I had to do the Pythagorean Theorem to get a diagonal so I knew what size log to go find.”

“And then when I started driving using that to calculate MPG and when I got a job using math to calculate how much money I was making.”

“I was just driving home last night when it first started to snow. And my driveway’s kind of steep, and I pulled up and tried to park, and I just kept sliding down. And I said, ‘well, why can’t I park?’ And I’m like, ‘well, because the snow’s there and the snow’s slick and it reduces the friction so gravity pulls me down.’ And that just kind of flashed through my head and I said, ‘well, I guess I’ll park on the street.’”

It is apparent that Schuyler (who exhibits broader interdisciplinary affinity) was more apt to connect classroom content with his everyday life. That is not to say that Adlai did not see classroom topics as relevant to his life as well, but when doing so he saw it much more narrowly along the lines of his academic career. Viewed in the context of expectancy-value research, Schuyler sees intrinsic value to academic topics while Adlai sees utility value (Eccles and Wigfield, 2002; Hulleman et al., 2008). This could explain the quantitative correlation between seeing topics as relevant to their
lives and interdisciplinary affinity. Students with interdisciplinary affinity see many more opportunities to connect classroom content with their lives.

These results have some implications for teachers. One is that teachers should endeavor to make real-life connections that are relevant for their students. This is important for interdisciplinary affinity and identity development. But these cases also illustrate how important it is for teachers to be aware of their students’ interests and values. Adlai and Schuyler think of real-life relevance in different ways and what is a real-life connection for one, might not be for the other. It also implies the need for students to have a variety of experiences from which they can draw connections.

Figure 4.3 updates the concept map shown earlier by outlining the importance of real-life topics in physics class. Real-life topics in physics class are important for developing physics interest which is related to students’ interdisciplinary affinities.
Level of conceptual understanding required

While questions about real-life relevance were explicitly asked in site visit interviews, questions about the level of conceptual understanding required in class were not. However, since the quantitative results showed its importance to interdisciplinary affinity, the follow-up interviews included questions asking about conceptual understanding in their high school physics class.

It is interesting that both students (Schuyler and Adlai) seemed confused about the question and the meaning of “conceptual understanding” had to be discussed before describing its importance in the physics class. Schuyler and Adlai had slightly different ways of discussing conceptual understanding.

Adlai’s idea of conceptual understanding was contrasted with memorizing a procedure. To him, conceptual understanding meant a qualitative comprehension of physical phenomena.

“You can memorize the process about like [sic] a problem is, but if you don’t understand the idea behind it or how to like, how you get to that kind of an answer, you’re not really going to understand what you’re doing. But I feel for any problem it’s really, it’s more important to know conceptually what to bring than the actual process. I mean, you can get the process later [emphasis added].”

Adlai’s description is similar to published definitions of conceptual understanding that emphasize an “integrated and functional” understanding of the topic and where “Students with conceptual understanding know more than isolated facts and methods” (National Research Council, 2001, p. 118). Conceptual understanding requires the integration of facts and methods, which is also a key component of interdisciplinarity. Adlai sees conceptual understanding as the real knowledge. Problem solving
procedures are just supplemental to conceptual understanding; “you can get the process later.” In Adlai’s comments, it is evident that conceptual understanding goes beyond mere completion of a task. Instead it requires grasping the meaning behind the procedure.

A key idea that is connected to conceptual understanding, and will be used several times as an interpretive tool in this chapter, is mastery orientation. Pintrich et al. (1993) argue that conceptual change theory (Posner et al., 1982; Strike and Posner, 1992) needs to consider motivations, classroom contexts, and student interests. One of these is goal orientation which has two dispositions: mastery and performance (Pintrich et al., 1993). Students with mastery orientation “focus on learning, understanding, and mastering the task.” Performance oriented students are concerned with “obtaining a good grade or besting others.”

Though Schuyler’s framing of conceptual understanding is different than Adlai’s, it also connects to a mastery orientation.

“[The teacher] would teach something and he’d give like problems to it and you could do it without his help or anyone else’s help. You could do it and understand what you were doing.”

“I think it would be if you’re trying the problem and someone got it and they needed help in like every single step. And I mean, sometimes, sometimes, ah, I would need help like starting the problem or I’d get halfway through a problem and get a little confused, but one question would usually solve that. That’s not exactly what I’m talking about with misunderstanding but like someone at every single step isn’t quite sure exactly what to do.”

Schuyler is describing performance on classroom tasks, but it is clear that his idea
of conceptual understanding requires more than successfully completing the task. It requires understanding to the point that the student has some level of mastery of the material.

Integrating theory, quantitative data, and qualitative data, it appears that mastery orientation is an important link between a focus on conceptual understanding in physics class and interdisciplinary affinity. Conceptual understanding requires students to focus on deeper meanings beyond task performance. The mastery oriented student, because of their desire to obtain deeper understanding, which often requires integrating ideas, is more likely to have interdisciplinary affinity. As seen in Chapter 3, mastery orientation is a significant predictor that, compared to other predictors, accounts for much of the variance in interdisciplinary affinity. These relationships are illustrated in Figure 4.4. This figure updates Figure 4.3 by adding the relationships between having a conceptual understanding focus in class, mastery orientation, and interdisciplinary affinity explored in this section. Also, an arrow from real-life topics to mastery orientation was added based on mastery orientation literature (Ames, 1992; Pintrich et al., 1993) which suggests an emphasis on real life topics can also foster mastery orientation. This offers an alternative route for real-life topics to influence the development of students’ interdisciplinary affinity.

Questions required several steps of calculations

While this was one of the more surprising results of Chapter 3, the qualitative data indicate that its link to interdisciplinary affinity is also partly through mastery orientation.

On this topic, Adlai’s comments give the clearest insight into connections with interdisciplinary affinity. (Schuyler’s comments on multi-step problems were focused on how clear the problem’s directions were.) When asked about the frequency of
multi-step problems in physics, Adlai said the teacher did not employ them often. Adlai supposed this was to help the weaker students in the class.

“There was probably a couple thrown in there that, you know, required a couple more steps that really tested to see who knew and who didn’t [emphasis added].”

“I feel like [a multi-step problem] tests to see if the student is actually learning more. I mean, some of the single step things, you know, you can just look up this equation and then yeah, you can figure that out, but you might not necessarily understand the process behind it. Whereas like a multiple step calculation you might have to understand what you’re doing and how you’re doing it and why you’re doing it [emphasis added].”

Here, as in the previous section, the distinction is an emphasis on understanding rather than memorizing a procedure. To Adlai, a multi-step problem tests deeper understanding because the student cannot simply plug a number into a formula. They have to be able to think more deeply about the problem.
Individual work in class

During the building of the interdisciplinary affinity model (Table 3.3), individual work in class was omitted due to the significance threshold used ($p < 0.01$). However, it was a significant, positive predictor in earlier models and was significant at the $p < 0.05$ level in the final model. Therefore, the follow-up interviews with Schuyler and Adlai included questions to probe this link. The qualitative data indicate that a link between individual work in class and interdisciplinary affinity is also closely tied with mastery orientation.

Both Schuyler and Adlai gave similar responses about individual work. Both reported that their physics class included both individual and group work. Both said the benefit of working in a group or with a partner was that each could help the other with difficulties and catch errors. But Adlai’s strong preference for group work is the clearest link to interdisciplinary affinity. Without equivocating, he expressed his reasons for preferring group work.

“Because it’s like if I get stuck and I’m alone it’s not as easy to figure it out as it is like if you have people help you through it that can help teach what you’re having trouble with. It’s always better to work in groups . . . in my opinion.”

Schuyler’s thoughts were very similar.

“When there was someone who did want to actually help and actually do it, then it was nice to have them there because we kind of both would do it and then check each other’s work and do the next part and check each other’s work. And if one of us forgot something or failed at a part, then the other person said, ‘Oh hey, you forgot this’ and then it kind of kept you on track.”
Since Adlai is an excellent student, it would not appear that his preference for group work and the help that comes with it is because he struggles academically. Instead, it seems that this is due to his desire to perform as well as possible academically and, in doing so, fulfill his performance orientation. When asked why the teacher would assign group or individual work, Adlai said,

“I feel like when you work alone it’s kind of like a test of your skill, like to see if you’re really understanding. . . Like if you’re actually learning this and you can see what you have problems with on your own. Whereas with a group you can kind of complete each other’s mistakes, or like what you don’t know somebody else can help you with.

This quote from Adlai makes it evident that individual work is connected to mastery orientation. To Adlai, individual work was a test of understanding. Group work was a way to get the answer while depending on other group members for help without having to completely master the material. To both Schuyler and Adlai, group work was a way to depend on others for help. So requiring individual work might help students develop mastery orientation since they can not depend on their classmates to complete the task. This is supported by the work of Velez et al. (2014) who found individual work was a significant predictor of the same science and math mastery orientation. (That study also used the SaGE data.)

Group work is vital to active learning and is linked to conceptual understanding (Prince, 2004; Alexopoulou and Driver, 1996). In fact, the frequency of having students teach other was also nearly significant ($0.05 > p > 0.01$) in the interdisciplinary affinity model of Chapter 3. So this result does not argue that group oriented active learning pedagogies should be abandoned. It only indicates that some amount of individual work is valuable to developing mastery orientation and interdisciplinary
affinity.

The last two sections (multi-step problems and individual work) are added to the concept map in Figure 4.5. These two are also connected to mastery orientation which provides a link to interdisciplinary affinity.

4.3 Mastery orientation in the quantitative data

In order to test the mastery orientation interpretation presented in this chapter, the quantitative data from SaGE was used. The qualitative data link physics classroom characteristics to mastery orientation. They also suggest the link between mastery orientation and interdisciplinary affinity. However, the quantitative data offer a way of confirming that link.

A construct representing mastery orientation was built of responses to survey items asking about career satisfaction (Velez et al., 2014). In particular, it asked students to rate, on an anchored, five-point scale from strongly disagree to strongly agree, the importance of the following to their career satisfaction: (1) inventing/designing things, (2) developing new knowledge and skills, and (3) applying math and science. This mastery orientation was added to the regression model predicting interdisciplinary affinity. The result is shown in Table 4.1 (Compare to Table 3.3). When included in the model, mastery orientation had the strongest standardized coefficient, was the most significant predictor, and the adjusted $R^2$ of the model increased from 0.06 to 0.12, indicating that mastery orientation is an important factor in understanding students’ interdisciplinary affinity.
Figure 4.5: Concept map following Figure 4.4 adding the relationships between multi-step problems and individual work and mastery orientation.
### Table 4.1: Regression model predicting interdisciplinary affinity with STEM mastery orientation included (N=2,066). **: p<0.01; ***: p<0.001; ns: not significant.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Est.</th>
<th>Std. Err.</th>
<th>β</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intercept</strong></td>
<td>1.93</td>
<td>0.13</td>
<td></td>
<td>***</td>
</tr>
<tr>
<td><strong>Controls</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Race, gender, and SES</td>
<td></td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>Math scores†</td>
<td>-0.20</td>
<td>0.15</td>
<td>-0.05</td>
<td>ns</td>
</tr>
<tr>
<td>Science scores‡</td>
<td>-0.01</td>
<td>0.18</td>
<td>0.00</td>
<td>ns</td>
</tr>
<tr>
<td>English scores‡</td>
<td>0.58</td>
<td>0.14</td>
<td>0.14</td>
<td>***</td>
</tr>
<tr>
<td><strong>STEM mastery orientation</strong></td>
<td>0.08</td>
<td>0.01</td>
<td>0.25</td>
<td>***</td>
</tr>
<tr>
<td><strong>Physics classroom factors</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topics were relevant to their life‡</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“Rarely”</td>
<td>0.08</td>
<td>0.07</td>
<td>0.04</td>
<td>ns</td>
</tr>
<tr>
<td>“Monthly”</td>
<td>0.08</td>
<td>0.07</td>
<td>0.04</td>
<td>ns</td>
</tr>
<tr>
<td>“Weekly”</td>
<td>0.16</td>
<td>0.06</td>
<td>0.09</td>
<td>**</td>
</tr>
<tr>
<td>“Daily”</td>
<td>0.19</td>
<td>0.06</td>
<td>0.11</td>
<td>**</td>
</tr>
<tr>
<td>Level of conceptual understanding required</td>
<td>0.07</td>
<td>0.02</td>
<td>0.09</td>
<td>***</td>
</tr>
<tr>
<td>Questions required several steps of calculations</td>
<td>0.20</td>
<td>0.04</td>
<td>0.11</td>
<td>***</td>
</tr>
</tbody>
</table>

Adjusted R^2 = 0.12

† A composite of class grades and standardized test scores.
‡ Reference level is “never.”
4.4 Conclusions

The first question to answer with this qualitative study was why interdisciplinary affinity has a stronger link to physics identity than to math identity. The results indicate that interest is the key. As discussed in Chapter 2, interest is one of the key components of a disciplinary identity such as math or physics identity (Hazari et al., 2010b; Cribbs et al., 2012; Potvin and Hazari, 2013). Since interdisciplinary affinity captures, to some extent, students' breadth of interest, it will therefore be linked more strongly to academic areas which those students view as engaging their interests. Students interviewed in this study saw physics identity as much more interest focused than math identity. So it appears that the quantitative results can be explained by the engagement of interests. Students with interdisciplinary affinity see physics as open to engaging their broad interests.

The dependence of identity on performance is closely related to students' conceptions of the openness of that identity. The more dependent identity is on performance, the less likely it is that someone could have that identity. In other words, performance oriented identities are more likely constrained to students with inherent abilities, especially to those who have an entity view of intelligence. But an entity view is less likely to result in interest (Dweck and Molden, 2005). If students like those in this study saw math as more dependent on ability, math will be less likely to be included in an interdisciplinary affinity.

The second question focused on the physics classroom characteristics that predict interdisciplinary affinity in the quantitative model (Table 3.3). These were (1) topics relevant to their life, (2) focus on conceptual understanding, (3) doing multi-step problems, and (4) doing individual work. (Although the last item did not meet the significance threshold established for inclusion in the quantitative model,
the qualitative data and other literature suggest it is a real and interesting result.)

Relevance to students’ lives is also linked to interests. Especially in the case of Schuyler, interests and real-life relevance were inexorably linked. Though his idea of real-life relevance was different than Schuyler’s, Adlai’s interests were also closely tied to his real-life relevance. Again, since interdisciplinary affinity is tied to broad interests, it is apparent that students’ broad interests will be linked to how often they can connect to their real-life. Educators could help foster interdisciplinary affinity by showing students how their field intersects the students’ real-life interests. It is worth repeating that this is not the same for every student. Though relevance to real-life was important to both Adlai and Schuyler, one was focused on academics while the other on the experiences of daily life. It is vital that educators recognize what each student values and help them make those personalized connections.

The other three classroom features are linked to interdisciplinary affinity through features encouraging mastery of physics material. Mastery orientation was found to be a strong predictor of interdisciplinary affinity in Chapter 3. As discussed in Chapter 1, interdisciplinarity is not a shallow knowledge across disciplines. It requires mastery in at least one discipline and the ability to think critically in areas outside of expertise (Borrego and Newswander, 2010). Requiring conceptual understanding is therefore vital to interdisciplinary affinity. Both Schuyler and Adlai were somewhat vague in the details of what conceptual understanding means. But it was clear that they explained conceptual understanding in class through mastery. For Adlai especially, it clearly meant knowing more than a recipe for getting an answer.

In a very similar way, individual work takes away the assistance that having classmates work together brings. Working independently requires individual mastery and, as Adlai said, it lets you “target what you need more help with.” Educators should work to find a balance between group work – vital for active, constructivist
learning – and individual work which can grow student mastery by removing the safety net of classmates.

Multi-step problems also require mastery. It means synthesizing separate ideas and knowing which bits of information are required to solve problems. Adlai said multi-step problems test the ability of students because of this added difficulty.

The two research questions tackled in this chapter and the seemingly different classroom characteristics considered boil down to two simple concepts. Interest and mastery orientation are integral to interdisciplinary affinity. And significant quantitative links outlined in Chapter 3 are essentially connected through these two concepts. Besides employing specific pedagogical tools discussed here, educators should be aware of the deeper levels of interest and mastery orientation needed and should look for ways to foster these within students.

The framework of incremental and entity views of intelligence also offers interpretations of this data. Although not discussed much in this chapter, it does help explain why physics identity is more closely related to interdisciplinary affinity than math identity. It might also help explain the connections between specific physics classroom characteristics and interdisciplinary affinity. Dweck and Molden (2005) outline several areas in which an incremental view of intelligence is connected to self-regulated learning strategies and mastery orientation motivations. Future research could explore the connection between interdisciplinary affinity, the physics classroom, and views on intelligence.

Returning to quantitative data, the following chapter will continue this study by improving the measurement of interdisciplinary affinity. It will use theory to develop questions intended to measure different dimensions of interdisciplinary affinity. It will further explore the connections between interdisciplinary affinity and physics identity.
In Chapter 3, results showed a positive, significant correlation between interdisciplinary affinity and physics identity. Among the limitations of that work are that

Comic source: “Piled Higher and Deeper” by Jorge Cham, www.phdcomics.com
interdisciplinary affinity was defined by only two survey questions and physics identity by four survey items. Also, that work did not investigate any specific questions pertaining to how interdisciplinary affinity is connected to the different dimensions of physics identity. Therefore, work for this chapter used a new data set to better define the interdisciplinary affinity construct, the physics identity construct, and further investigate the quantitative links between interdisciplinary affinity and physics identity.

This chapter is guided by two research questions:

Q1. How can the quantitative interdisciplinary affinity indicator be improved?

Q2. How is the new interdisciplinary affinity indicator connected with physics identity and with the interest and recognition components of physics identity?

5.1 Methods: The OPSCI study and data analysis

This study draws from survey data obtained as part of the Outreach Programs and Science Career Intentions (OPSCI) project (NSF Grant No. 1161052). The goal of this project was to investigate pre-college outreach-related factors and their influence on the choice of STEM major and on career interest. Colleges and universities with a Science Talent Expansion Program (STEP) were asked to participate. These institutions have programs seeking to increase the number of STEM graduates. Of these, 27 institutions returned 15,847 individual surveys. Like SaGE, this study sought freshman students in introductory English classes to obtain the broadest range of career intentions. There were a few exceptions in which classes other than English were chosen. In these cases, they were freshman courses that serve all or most incoming students.
The survey asked about a variety of topics including physics identity and hypothesized qualities of interdisciplinarity. For reasons outlined by Potvin and Hazari (2013), this survey focused only on the interest and recognition dimensions of physics identity. Factor analysis confirmed the clear distinction of the two dimensions. The interest component of physics identity was constructed from students’ responses to “I am interested in learning more about physics,” “Topics in physics excite my curiosity,” and “I enjoy learning about physics.” Recognition was built from responses to “My physics teacher sees me as a physics person,” “My family sees me as a physics person,” “Others ask me for help in physics,” and “My friends/classmates see me as a physics person.”

The items used to measure interdisciplinary affinity were guided primarily by the work of Borrego and Newswander (2010) who analyzed interdisciplinary research grants and defined four characteristics of interdisciplinarity. The OPSCI survey included 13 items; intentionally designed to assess “disciplinary grounding,” “integration,” “communication and translation,” and “critical awareness.” A list of the 13 items and their corresponding dimension of interdisciplinarity is shown in Table 5.1. All identity and interdisciplinary affinity items asked for responses on an anchored six point scale from strongly disagree to strongly agree.

The particular items were informed by the prior work described in Chapter 3 and discussion among the OPSCI team members. Two of the items, “I identify relationships between topics from different courses” and “I hope to gain general knowledge across multiple fields,” came from the work in Chapter 3. They were included here to maintain a link to that previous work. Other ideas came from a small pilot study (also described in Chapter 3) which was conducted in an introductory physics class. This consisted of an open ended survey, that asked students to respond to the two previously used items and asked for the reasons behind their answers. For example,
Table 5.1: List of interdisciplinary related items included on the OPSCI survey including the dimension of interdisciplinarity each was hypothesized to fit.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disciplinary</td>
<td>“I am certain of my chosen career path”</td>
</tr>
<tr>
<td>Grounding</td>
<td>“Being an expert in my chosen field of study is important to me”</td>
</tr>
<tr>
<td>Integration</td>
<td>“Being ‘well rounded’ is important to me”</td>
</tr>
<tr>
<td></td>
<td>“It is fun to see how STEM courses overlap with each other”</td>
</tr>
<tr>
<td></td>
<td>“It is fun to see how STEM courses connect with non-STEM courses”</td>
</tr>
<tr>
<td></td>
<td>“I hope to gain general knowledge across multiple fields”</td>
</tr>
<tr>
<td></td>
<td>“I identify relationships between topics from different courses”</td>
</tr>
<tr>
<td></td>
<td>“A lot of the high school courses I took are useless”</td>
</tr>
<tr>
<td>Communication</td>
<td>“My friends have different interests than I do”</td>
</tr>
<tr>
<td>and Translation</td>
<td>“Talking with people who have different interests than me is fascinating”</td>
</tr>
<tr>
<td></td>
<td>“When working in groups, I prefer teammates who are like me”</td>
</tr>
<tr>
<td>Critical Awareness</td>
<td>“People in my intended major have biases”</td>
</tr>
<tr>
<td></td>
<td>“People in my intended major could learn a lot from other fields”</td>
</tr>
</tbody>
</table>

\textsuperscript{a} included in the SaGE survey and used in Chapter 3
\textsuperscript{b} reverse coded
besides informing the construction of several items, the pilot study led to the inclusion of “Being ‘well rounded’ is important to me.”

The final OPSCI survey was administered to 57 students to establish test-retest reliability. Pearson correlations were calculated for continuous variables with a mean of 0.73 for the entire survey. In particular, the items used for physics identity averaged 0.82 and the 13 items intended to measure interdisciplinary affinity averaged 0.58. Of these, four items that were chosen to represent interdisciplinary affinity in the final analysis had a test-retest correlation of 0.63.

To answer research question 1, exploratory factor analysis (EFA) was employed to see how the survey items listed in Table 5.1 grouped into factors. Poorly loading items were removed and factors were evaluated for face validity. In addition, factors were correlated with students’ interest in a range of academic fields to support concurrent criterion-related validity of the measurement of interdisciplinary affinity.

Research question 2 required analyzing how the resulting interdisciplinary affinity measure correlated with physics identity and the components of physics identity. As in Chapter 3, statistical analyses were done using R version 2.15.3 (R Core Team, 2013) and the significance threshold used was \( p < 0.01 \). The code used for the analyses in this chapter is provided in Appendix E.

5.2 Results and Discussion

The first step was to establish a valid and more complete definition of interdisciplinary affinity than was previously used. To accomplish this, exploratory factor analysis was used to build a measure of interdisciplinary affinity from the items shown in Table 5.1. Note that the table only represents the theory behind the work. If the data were to confirm the framework of Borrego and Newswander (2010), results would
show four factors with the individual survey items falling into groups as shown in Table 5.1.

To begin, all the items shown in Table 5.1 were entered in the EFA except the two referring specifically to STEM courses. It was decided that the best measure of interdisciplinary affinity should not have any bias towards or against particular disciplines, so any reference to specific academic fields would be problematic. The remaining eleven items were loaded onto four factors. After removing poorly loading items and reducing the number of factors accordingly, the final result was seven items loading onto two factors. These results are shown in Table 5.2. One factor, called “Expert”, consisted of the items “I am certain of my chosen career path,” “Being an expert in my chosen field of study is important to me,” and “Being ‘well rounded’ is important to me.” The second, called “Integration”, consisted of “I identify relationships between topics from different courses,” “I hope to gain general knowledge across multiple fields,” “Talking with people who have different interests than me is fascinating,” and “People in my intended major could learn a lot from other fields.” The first two of these integration items were used in Chapter 3 which supported the validity of these two items and allowed some continuity in the research process.

The result from this analysis was that the items were not able to validate the four components of interdisciplinarity presented by Borrego and Newswander (2010). The “Integration” factor includes survey items from across three of the four hypothesized components of interdisciplinarity. Somewhat surprising was that being “well rounded” was factored with the two items intended to measure “Disciplinary Grounding.” A possible explanation is that, while some students associate being “well rounded” with interdisciplinary integration, it may also transcend that definition in students’ minds because being “well rounded” is so emphasized in education contexts as being a beneficial outcome of education. In other words, when students consider
<table>
<thead>
<tr>
<th>Statement</th>
<th>“Integration”</th>
<th>“Expert”</th>
</tr>
</thead>
<tbody>
<tr>
<td>“I am certain of my chosen career path”</td>
<td>-0.202</td>
<td>0.670</td>
</tr>
<tr>
<td>“Being an expert in my chosen field of study is important to me”</td>
<td>0.100</td>
<td>0.641</td>
</tr>
<tr>
<td>“Being ‘well rounded’ is important to me”</td>
<td>0.169</td>
<td>0.486</td>
</tr>
<tr>
<td>“I hope to gain general knowledge across multiple fields”^a</td>
<td>0.620</td>
<td></td>
</tr>
<tr>
<td>“I identify relationships between topics from different courses”^a</td>
<td>0.499</td>
<td>0.264</td>
</tr>
<tr>
<td>“Talking with people who have different interests than me is fascinating”</td>
<td>0.779</td>
<td></td>
</tr>
<tr>
<td>“People in my intended major could learn a lot from other fields”</td>
<td>0.805</td>
<td></td>
</tr>
</tbody>
</table>

^a included in the SaGE survey and used in Chapter 3

Table 5.2: Results of exploratory factor analysis of the survey items used in this study to build an interdisciplinary affinity measure. Contrast with hypothesized structure shown in Table 5.1
being “well rounded,” they may see it as a goal they want to achieve in their education (like being an expert in their chosen field of study) rather than the particulars of what it means in the context of interdisciplinary integration. This is supported by the distribution of student answers to this item which is skewed toward “strongly agree” in the same way in which the other two items in our “Expert” factor are. Figure 5.1 shows the histogram of responses to this item, illustrating the skewed distribution.

On the other hand, the survey items that factored into “Integration” all exhibited an approximately normal distribution. The items in the “Integration” factor come from across three of the hypothesized interdisciplinary components of Table 5.1. This could mean that distinctions between these components cannot be found by these survey items or that these distinctions do not exist. It is also possible that college students (mostly freshmen) have not developed the expertise to recognize the nuance of Borrego’s factors, which emerged from a study of research grants.

To further validate the measure of interdisciplinary affinity, correlations were calculated between interdisciplinary affinity and interests in a variety of academic topics. On the OPSCI survey, a series of questions asked students to rate their interest in the following areas, “languages (including English),” “physical sciences,” “athletics,” “biological and life sciences,” “math and computer science,” “social studies,” “art, music, theater, etc.,” and “engineering.” A factor analysis showed that these items factored into the following five categories: (1) science (physical and biological/life), (2) math/engineering, (3) arts (fine arts and languages), (4) social studies, and (5) athletics. The loadings of the factor analysis are shown in Table 5.3.

Responses to these five categories were averaged to measure breadth of interests (a higher rating indicates higher interests in more areas). The “Integration” factor was significantly and positively correlated with broad interests ($r = 0.38, p < 0.001, n = 12,605$). While “Expert” was also significantly correlated with broad interests,
Figure 5.1: Histogram of responses on the OPSCI survey to the item “Being well-rounded is important to me.” Strongly disagree = 0, strongly agree = 5.
Table 5.3: Results of exploratory factor analysis of the survey items gauging interests in various academic fields.

<table>
<thead>
<tr>
<th>Field</th>
<th>“Science”</th>
<th>“Math/Engineering”</th>
<th>“Arts and Languages”</th>
<th>“Social Studies”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Languages (including English)</td>
<td>0.130</td>
<td></td>
<td></td>
<td>0.602</td>
</tr>
<tr>
<td>Physical sciences</td>
<td>0.882</td>
<td></td>
<td></td>
<td>-0.106</td>
</tr>
<tr>
<td>Athletics†</td>
<td>0.102</td>
<td></td>
<td></td>
<td>0.214</td>
</tr>
<tr>
<td>Biological and life sciences</td>
<td>0.705</td>
<td>-0.182</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Math and computer science</td>
<td>0.215</td>
<td></td>
<td></td>
<td>0.477</td>
</tr>
<tr>
<td>Social studies</td>
<td>-0.113</td>
<td></td>
<td></td>
<td>0.248</td>
</tr>
<tr>
<td>Art, music, theater, etc.</td>
<td>0.125</td>
<td></td>
<td></td>
<td>0.539</td>
</tr>
<tr>
<td>Engineering</td>
<td></td>
<td></td>
<td></td>
<td>1.019</td>
</tr>
</tbody>
</table>

† Athletics did not load with any of the four factors so was left as its own factor.
the correlation was much smaller \((r = 0.18, p < 0.001, n = 12,939)\). This difference was statistically different at the \(p < 0.001\) level. It is likely that, though a certain degree of disciplinary grounding is required for interdisciplinarity, it is also a characteristic of a large number of students who have no interdisciplinary affinity. As such, including it in a quantitative measurement of interdisciplinary affinity is problematic. Since integration is regarded in the literature as the essential component of interdisciplinarity (Boix Mansilla and Dawes Duraising, 2007; Borrego and Newswander, 2010; Lattuca and Knight, 2010), and since it has the benefits of connecting to prior work, as well as of face and criterion-related validity, this chapter used only the four survey items of the “Integration” factor as the measure of interdisciplinary affinity.

Answering the second research question required building multivariate linear models with physics identity and its components as outcomes. Though the OPSCI survey did not include items measuring agency and epistemic beliefs, it did include control variables comparable to those used in Chapter 3. These include gender, socio-economic status (SES) related factors, grades, enjoying physics class, and the role of science in family life. Table 5.4 shows a model with physics identity as the outcome and interdisciplinary affinity and controls as predictors. The result is very similar to the results of Chapter 3 (see Table 3.1). Interdisciplinary affinity is a significant, positive predictor of physics identity \((\beta = 0.17, p < 0.001)\). Gender \((\beta = 0.23, p < 0.001)\) and physics grades \((\beta = 0.06, p < 0.001)\) were significant controls along with math \((\beta = 0.10, p < 0.001)\) and English \((\beta = -0.04, p < 0.001)\) scores. Two family background controls were also significant: having a father with a STEM related career \((\beta = 0.04, p < 0.01)\) and a family viewing science as a hobby \((\beta = 0.05, p < 0.001)\). These results confirm that even when demographics, family support for science, and academic performance are controlled, interdisciplinary affinity is a significant, positive predictor of physics identity.
Table 5.4: Regression model predicting physics identity (N=6,960).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Est.</th>
<th>Std. Err.</th>
<th>( \beta )</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-2.10</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Race and SES</td>
<td></td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>Gender (0 = Female, 1 = Male)</td>
<td>0.73</td>
<td>0.03</td>
<td>0.23</td>
<td>***</td>
</tr>
<tr>
<td>Physics grade</td>
<td>0.12</td>
<td>0.03</td>
<td>0.06</td>
<td>***</td>
</tr>
<tr>
<td>Math scores(^\dagger)</td>
<td>1.11</td>
<td>0.13</td>
<td>0.10</td>
<td>***</td>
</tr>
<tr>
<td>Science scores(^\dagger)</td>
<td>0.41</td>
<td>0.17</td>
<td>0.03</td>
<td>ns</td>
</tr>
<tr>
<td>English scores(^\dagger)</td>
<td>-0.57</td>
<td>0.14</td>
<td>-0.04</td>
<td>***</td>
</tr>
<tr>
<td>Mother has STEM related career</td>
<td>0.02</td>
<td>0.14</td>
<td>0.00</td>
<td>ns</td>
</tr>
<tr>
<td>Father has STEM related career</td>
<td>0.13</td>
<td>0.04</td>
<td>0.04</td>
<td>**</td>
</tr>
<tr>
<td>Family science hobbies</td>
<td>0.25</td>
<td>0.06</td>
<td>0.05</td>
<td>***</td>
</tr>
<tr>
<td>Liked their physics class</td>
<td>0.62</td>
<td>0.02</td>
<td>0.45</td>
<td>***</td>
</tr>
<tr>
<td>Interdisciplinary Affinity</td>
<td>0.31</td>
<td>0.02</td>
<td>0.17</td>
<td>***</td>
</tr>
</tbody>
</table>

Adjusted \( R^2 \) = 0.42

\(^\dagger\) A composite of class grades and standardized test scores.

But this chapter also asks how interdisciplinary affinity is related to the subconstructs of physics identity: interest and recognition. To examine these questions, similar regression models were built with only physics interest and physics recognition as outcomes. Models focusing on physics interest (see Table 5.5) and recognition (see Table 5.6) as outcomes showed similar results with variations in effect size. The results of the qualitative analysis in Chapter 4 suggested that interdisciplinary affinity is more prominently connected to physics identity through interest rather than recognition. The two models presented here also show difference with interdisciplinary affinity being a stronger predictor of physics interest \((\beta = 0.18, p < 0.001)\) than of physics recognition \((\beta = 0.15, p < 0.001)\). This difference is statistically significant at the \( p < 0.001 \) level. It is interesting to note that academic performance indicators are stronger predictors in the recognition model, while gender, liking physics class, and interdisciplinary affinity are all stronger in the interest model.
Table 5.5: Regression model predicting physics interest (N=6,960).

**: \( p < 0.01 \); ***: \( p < 0.001 \); ns: not significant.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Est.</th>
<th>Std. Err.</th>
<th>( \beta )</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-1.83</td>
<td>0.16</td>
<td></td>
<td>***</td>
</tr>
<tr>
<td>Race and SES</td>
<td></td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>Gender (0 = Female, 1 = Male)</td>
<td>0.83</td>
<td>0.04</td>
<td>0.23</td>
<td>***</td>
</tr>
<tr>
<td>Physics grade</td>
<td>0.08</td>
<td>0.03</td>
<td>0.04</td>
<td>ns</td>
</tr>
<tr>
<td>Math scores†</td>
<td>0.90</td>
<td>0.14</td>
<td>0.08</td>
<td>***</td>
</tr>
<tr>
<td>Science scores‡</td>
<td>0.30</td>
<td>0.19</td>
<td>0.02</td>
<td>ns</td>
</tr>
<tr>
<td>English scores‡</td>
<td>-0.60</td>
<td>0.15</td>
<td>-0.04</td>
<td>***</td>
</tr>
<tr>
<td>Mother has STEM related career</td>
<td>0.02</td>
<td>0.05</td>
<td>0.01</td>
<td>ns</td>
</tr>
<tr>
<td>Father has STEM related career</td>
<td>0.13</td>
<td>0.04</td>
<td>0.04</td>
<td>**</td>
</tr>
<tr>
<td>Family science hobbies</td>
<td>0.25</td>
<td>0.06</td>
<td>0.04</td>
<td>***</td>
</tr>
<tr>
<td>Liked their physics class</td>
<td>0.70</td>
<td>0.02</td>
<td>0.46</td>
<td>***</td>
</tr>
<tr>
<td>Interdisciplinary Affinity</td>
<td>0.35</td>
<td>0.02</td>
<td>0.18</td>
<td>***</td>
</tr>
</tbody>
</table>

Adjusted \( R^2 = 0.41 \)

† A composite of class grades and standardized test scores.

---

Table 5.6: Regression model predicting physics recognition (N=6,960).

**: \( p < 0.01 \); ***: \( p < 0.001 \); ns: not significant.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Est.</th>
<th>Std. Err.</th>
<th>( \beta )</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-2.38</td>
<td>0.15</td>
<td></td>
<td>***</td>
</tr>
<tr>
<td>Race and SES</td>
<td></td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>Gender (0 = Female, 1 = Male)</td>
<td>0.63</td>
<td>0.03</td>
<td>0.20</td>
<td>***</td>
</tr>
<tr>
<td>Physics grade</td>
<td>0.16</td>
<td>0.03</td>
<td>0.08</td>
<td>***</td>
</tr>
<tr>
<td>Math scores†</td>
<td>1.32</td>
<td>0.13</td>
<td>0.12</td>
<td>***</td>
</tr>
<tr>
<td>Science scores‡</td>
<td>0.52</td>
<td>0.17</td>
<td>0.04</td>
<td>**</td>
</tr>
<tr>
<td>English scores‡</td>
<td>-0.54</td>
<td>0.14</td>
<td>-0.04</td>
<td>***</td>
</tr>
<tr>
<td>Mother has STEM related career</td>
<td>0.01</td>
<td>0.04</td>
<td>0.00</td>
<td>ns</td>
</tr>
<tr>
<td>Father has STEM related career</td>
<td>0.13</td>
<td>0.05</td>
<td>0.04</td>
<td>ns</td>
</tr>
<tr>
<td>Family science hobbies</td>
<td>0.25</td>
<td>0.06</td>
<td>0.05</td>
<td>***</td>
</tr>
<tr>
<td>Liked their physics class</td>
<td>0.54</td>
<td>0.02</td>
<td>0.39</td>
<td>***</td>
</tr>
<tr>
<td>Interdisciplinary Affinity</td>
<td>0.26</td>
<td>0.02</td>
<td>0.15</td>
<td>***</td>
</tr>
</tbody>
</table>

Adjusted \( R^2 = 0.42 \)

† A composite of class grades and standardized test scores.
5.3 Conclusions and Future Work

This chapter takes another step in the development of a quantitative measure of interdisciplinary affinity. While Chapter 3 used only two survey items, this work has now established four valid, reliable survey items for measuring interdisciplinary affinity. Unfortunately, the data did not confirm the theoretical framework of Borrego and Newswander (2010). Though the items used on the OPSCI survey were intended to map to the four hypothesized dimensions of interdisciplinarity, only one factor useful for measuring interdisciplinary affinity emerged instead of four. Additional work should be done to develop more survey items and try to distinguish different possible dimensions of interdisciplinary affinity. More pilot studies probing students’ conceptions of interdisciplinarity might suggest more key concepts by which students conceive of interdisciplinarity.

The OPSCI survey also included new items that can be used to better measure physics identity. Though physics interest and recognition have been found to be the vital components of physics identity (Potvin and Hazari, 2013), the SaGE survey used in Chapter 3 only included two items capturing interest and two for recognition. By using three items to represent physics interest and four for recognition, this work captures more variance of physics identity and is another important step in developing quantitative tools for measuring physics identity.

Results of the linear models showed that interdisciplinary affinity is a significant and positive predictor of physics identity as well as both interest and recognition components of identity. The physics identity model shows very similar results as those from Chapter 3. This only adds to the evidence that there is an interesting link between interdisciplinary affinity and physics identity. New results in this chapter revealed a stronger link of interdisciplinary affinity to physics interest that is consistent
with the qualitative results presented in Chapter 4.

These models also raised some interesting questions not directly related to the research questions. Perhaps unsurprisingly, physics grades and other academic performance indicators were more strongly linked to physics recognition than to interest. Also, liking their physics course led students to rate higher physics interest. There is also a slight difference in the strength of the gender predictor in the two models. These are interesting links that might be investigated further with qualitative methods to understand how physics interest is developed and recognition is manifest in individual students.
Chapter 6

Conclusions and Discussion

“Begin at the beginning, and go on till you come to the end: then stop.”
- The King of Hearts

Alice’s Adventures in Wonderland

This dissertation set out to define, understand, and measure a concept called interdisciplinary affinity and investigate its links to physics identity. There were two purposes. First, it would expand the horizons of research on both interdisciplinarity and physics identity. Second, it would offer physics educators insight into the development of interdisciplinary affinity and physics identity in high school students.

Chapter 1 introduced interdisciplinarity, placed it in its historical context and outlined the arguments for the importance of interdisciplinarity. Chapter 2 provided an overview of the theoretical frameworks of interdisciplinary education and research and that of physics identity. Also, it justified the need for a simple definition of interdisciplinarity that encompasses students interests and ideas. Labeling it “interdisciplinary affinity,” Chapter 3 examined a way of measuring it. It was shown that this measurement of interdisciplinary affinity has significant, interesting connections
to physics identity and several physics classroom pedagogies are significantly related to interdisciplinary affinity. Chapter 4 investigated these links using interviews with select students in a high school physics class that was also observed. Finally, Chapter 5 used another, national survey to further develop the measurement of interdisciplinary affinity and its connection to physics identity. This final chapter will summarize these results and comment on possible future work.

6.1 Summary of Findings

Interdisciplinarity has been a topic of interest to educators and researchers for about 40 years (Kockelmans, 1979a; Michel et al., 2011). While it has a heritage in the traditions of the liberal arts and general education, interdisciplinarity also has a place in the realm of vocationalism and training (Dare, 2001). Interdisciplinarity stresses the connections between subject areas and promotes a more holistic view of information. But it also fosters skills needed in various occupations. Because of this position straddling various philosophies of schooling and because of its desirable outcomes, it is an important concept for researchers and practitioners to understand.

Various frameworks have been used to understand interdisciplinarity. Two things emerge from these frameworks. First, most researchers acknowledge that a key idea when thinking about interdisciplinarity is “integration” (Klein and Newell, 1998; Lattuca and Knight, 2010). This includes integration of information and also points of view. An interdisciplinary researcher not only synthesizes information from multiple disciplines but also understands and appreciates the ways of thinking of other disciplines. Secondly, it is also apparent that a universally accepted definition of interdisciplinarity does not exist (Lattuca and Knight, 2010). While interdisciplinarity carries the general connotation of integration of multiple disciplines, specific defini-
tions vary based on the extent of that integration. For example, do new academic frameworks need to be established to truly call a research subject interdisciplinary? What characterizes true “integration”? 

Another issue with the state of research on interdisciplinarity is its limited scope. The literature emphasizes performance outcomes with little consideration of affective states. Therefore, this work defined “interdisciplinary affinity,” which was based on students’ interests in being interdisciplinary as well as their beliefs in their ability to be interdisciplinary. Also, the emphasis in the literature is on college education and on research. There is less research focusing on interdisciplinarity at the high school level and below. If interdisciplinarity is something needed in college students and graduates, interdisciplinary affinity is something that students should be developing in high school, particularly since affinities are more related to long-term engagement than task performances (Bandura, 1997; Hazari et al., 2010a). Therefore, this work also focused on high school experiences and beliefs during the time of transition to college.

A physics identity framework was used to connect interdisciplinary affinity to the subject of physics. This framework was drawn primarily from work by Hazari et al. (2010b) and from subsequent refinements outlined by Potvin and Hazari (2013). Because physics identity is strongly linked to physics career choice and because it captures students’ engagement with the field, it is a valuable framework to use when seeking to identify ways to engage a larger and more diverse population of students. Drawing from prior work, physics identity was measured using items that ask students about their interest in physics and how they feel recognized by others as a “physics person.”

Having developed and validated a preliminary measure of interdisciplinary affinity, the results of this work showed a relationship between interdisciplinary affinity
and physics identity. This positive and statistically significant relationship existed even when academic performance and student ideas about science and engineering were controlled. Even more intriguing was the fact that when the same factors were controlled in a linear model predicting math identity, interdisciplinary affinity was not a statistically significant predictor. This raised questions about how students view math and physics differently as well as questions regarding the relationship between interdisciplinary affinity and physics identity given the reputation physics has of isolation (National Science Board, 1998; Ortega and Antell, 2000; Van Leeuwen and Tijssen, 2000; Kessels et al., 2006).

The same data also showed relationships between several characteristics of high school physics classes and students’ interdisciplinary affinity. These were class topics relevant to students’ lives, the level of conceptual understanding required in the class, and questions requiring several steps of calculations. Results suggested that encountering these in a high school physics class might help students develop interdisciplinary affinity or better engage the students who have interdisciplinary affinity. Several of these are supported by research showing that at least one reason interdisciplinary pedagogy is successful because it engages students’ varied interests (Elmesky, 2005; Garcia et al., 2010; van der Veen, 2012).

To answer some of these questions raised by the initial quantitative results, qualitative data was employed through interviews. Focusing on three students taking a high school physics class, the qualitative data attempted to answer questions about the link between interdisciplinary affinity and physics identity (including why the link with physics identity is different than the link with math identity) and possible explanations for the links between the physics classroom and interdisciplinary affinity.

First, results showed that all the students discussed their conceptions of physics identity in terms of interest more often then when discussing math identity. Since in-
interest is a key component of interdisciplinary affinity, it seems likely that if students see physics identity developed through interest, it will have a stronger connection to interdisciplinary affinity. If students see math identity as primarily connected to performance and competence, they will be less likely to see it as relevant to their interdisciplinary affinity. The results suggested that interdisciplinary affinity is linked to physics identity because, despite stereotypes to the contrary, high school students that have interdisciplinary affinity see opportunities to engage their interests in physics topics.

In-depth interviews with the students also provided insight into connections between physics class and interdisciplinary affinity. Real-life topics offer even more ways for students to engage their interdisciplinary interests in physics class. Previous research has shown that real-life connections are connected to interests (Hulleman and Harackiewicz, 2009). In particular, they show students how physics topics connect to their other interests and values. A focus on conceptual understanding, the use of multi-step problems, and individual work all seem to be connected to students mastery of physics concepts. Literature stresses the importance of students’ mastery orientation (Ames, 1992; Eccles and Wigfield, 2002; Linnenbrink and Pintrich, 2002), and both quantitative and qualitative results suggest it is also connected to interdisciplinary affinity. This indirect link through mastery orientation might explain why these classroom characteristics were found to significantly predict interdisciplinary affinity in the linear models.

Finally, the measurement of interdisciplinary affinity was further refined based on theory to re-validate and further explicate its connections to physics identity. A new survey was developed that included several items hypothesized to capture nuances of interdisciplinary affinity. They were designed to align with four dimensions of interdisciplinarity outlined by Borrego and Newswander (2010). However, an ex-
ploratory factor analysis did not group the items in line with the theory. Instead, four items emerged that were consistent with the previous measure and held up to further validity testing. These were used as a measure of interdisciplinary affinity in linear models predicting physics identity, physics interest, and recognition as a physics person. Results confirmed the earlier results, showing a significant, positive relationship between interdisciplinary affinity and physics identity. Interdisciplinary affinity was also a significant, positive predictor in two other models with physics interest and recognition as outcomes. However, consistent with the conclusions of the qualitative results, the relationship to physics interest was stronger than that with recognition.

In sum, this work made the following key findings:

- It established a valid measurement of interdisciplinary affinity.
- Interdisciplinary affinity is significantly and positively related to physics identity, and the relationship is stronger than one with math identity.
- Several characteristics of high school physics classrooms are significantly related to interdisciplinary affinity.
- Mastery orientation provides an explanation for the link between the classroom and interdisciplinary affinity.

### 6.2 Limitations

As with any research, this work has some limitations. Some of these limitations can be addressed by future studies.

First, the cross-sectional quantitative data obtained from the SaGE and OP-SCI studies is limited in the questions it can answer. The data were obtained from
first year college students across the United States. While it has the advantage of statistical power and is representative of that section of the population, it is not representative of students who do not attend college or students from other nations. Also, the OPSCI study only included colleges which had received STEP grants. But more importantly, the quantitative data can not determine causation. The statistically significant relationships described in this work only describe correlation.

To address the problem of understanding causation, this work also employed qualitative data. The primary limitation of the qualitative data and results is that of generalization. First, the three students involved in the case study were all male. Second, though multi-ethnic, the students did not include African-American, Asian, or other minorities. Finally, the three students are unique individuals and their feelings and ideas, their backgrounds, and their school is not necessarily representative of all physics students. Therefore, though the qualitative results provide great insight into connections between factors, the results will not be the same for every student.

6.3 Future Work

These results offer a few paths for future research. Just as this dissertation had a dual purpose (developing a useful framework of interdisciplinary affinity and discovering practical insight for educators), future work can parallel these paths.

First more work can be done to further develop the interdisciplinary affinity framework. Future surveys should include more items intended to capture the subtleties of interdisciplinary affinity. Perhaps more iterations like that outlined in Chapter 5 will result in identifying separate components of interdisciplinary affinity. The items to be used on these surveys can be informed by theory and qualitative data. For example, more open-ended surveys and interviews with students can lend
insight into what students think interdisciplinarity is and how it connects to their interests and goals.

Also, researchers interested in interdisciplinarity should consider alternatives to the traditional ways of thinking of interdisciplinarity. Interdisciplinary affinity was a way of moving beyond a performance paradigm by considering students’ interests and beliefs. More research should be done on interdisciplinary self-efficacy, identity, and epistemic beliefs. There is also a need to expand research on interdisciplinarity to the high school level and below since most of the prior research is at the post-secondary level.

At the practical level, additional research is needed to connect high school experiences to interdisciplinarity and interdisciplinary affinity. Chapters 3 and 4 discussed a few classroom characteristics that were found to connect to interdisciplinary affinity. But the adjusted $R^2$ in the linear model was very low. It is likely that there are more home, school, and classroom factors that influence students’ interdisciplinary affinity. Exploratory studies like SaGE which use a national survey to discover connections might uncover more factors that influence the development of interdisciplinary affinity, especially if purposely designed to do so (neither SaGE nor OPSCI were primarily intended for this purpose). Of course, qualitative data can also provide insights towards answering these questions. Open-ended surveys and interviews probing students’ interdisciplinary affinities might uncover connections to their experiences in the classroom. These should also be expanded to include a broader population including women and other underrepresented populations.

There are also other theoretical frameworks that could be incorporated into interdisciplinary affinity research. These are discussed below. Researchers working in these areas might consider how interdisciplinary affinity might be relevant to their research interests.
Motivation

The concepts of mastery and performance orientation played an important role in the interpretation of the qualitative data. However, a quantitative measure of mastery orientation was also found to be related to interdisciplinary affinity in the quantitative data, lending support to the qualitative interpretation. However, the data sources (interviews and classroom observations) were limited in their ability to identify mastery orientation. Because it was not a focus of the research, there were no interview questions designed to identify the motivations of the students interviewed.

Future work in this area should draw on both quantitative and/or qualitative data to better understand the ways in which mastery orientation and interdisciplinary affinity are connected. For example, new surveys could draw from motivation research to include new items measuring mastery orientation and investigate connections to interdisciplinary affinity. Interviews with students could also shed light on how students’ motivations relate to their interdisciplinary affinity.

Self-Theories

Self-theories describe an individuals’ views on the nature of personal qualities (Dweck and Molden, 2005). In particular, is intelligence innate and unchanging (an entity perspective) or something that can be developed and improved over time with study and effort (an incremental view)? Students with entity views are more likely to give up in the face of difficulty or failure and avoid situations in which they might not succeed. However, those with incremental views are more likely to have mastery orientation and engage with new tasks (Dweck and Leggett, 1988; Dweck and Molden, 2005). Therefore, it is easy to see how a student with an incremental view might be more likely to have interdisciplinary affinity. The student with an incremental view
would be more likely to see interdisciplinarity as a challenge to pursue while the student with an entity view is more likely to stay within their academic comfort zone.

This work did not ask students about their views of knowledge. Future work should include entity and incremental views in qualitative and quantitative studies. The Implicit Theories of Intelligence Scale has been used to study Engineering students’ beliefs and their learning strategies (Stump et al., 2014). A similar study could elucidate the connections between classroom pedagogy and interdisciplinary affinity through student views of intelligence.

**Epistemology**

Investigations of students’ epistemic beliefs in the context of interdisciplinary affinity might also provide interesting avenues for research. It would be interesting to see what epistemic beliefs are correlated with interdisciplinary affinity. This would be a complicated question that probably overlaps with intelligence beliefs. At least one model of epistemic beliefs includes self-theories of intelligence (Schommer, 1990). Others recognize that these views of intelligence may be correlated with epistemic beliefs (Hofer and Pintrich, 1997).

In particular, the epistemic beliefs of students with interdisciplinary affinity would be interesting to explore. Research indicates epistemic beliefs are domain specific (Paulsen and Wells, 1998; Muis, 2004). Palmer and Marra (2004) found that students’ epistemic beliefs in science contexts differed from their epistemic beliefs in social sciences and humanities. It would be interesting to see how students who have affinities for different domains integrate the epistemic beliefs of those domains. If a student had a strong interdisciplinary affinity for both physics and a subject in the humanities, how would that student’s epistemic beliefs be different or similar in those
domains? How would those beliefs inform each other and evolve?

The results of this research provide signs for optimism that physics has opportunities to engage students through interdisciplinary affinity. Students do see ways in which physics can connect with their real-life experiences and other interests. There are ways in which teachers can design their physics classes to help foster interdisciplinary affinity. With more work exploring various connections between interdisciplinary affinity and other research frameworks, researchers can make more progress towards understanding what students think about interdisciplinarity and how educators can promote interdisciplinary affinity in their students.
Appendices
Appendix A  SaGE Survey

Clemson University
Engineering and Science Education

SaGE:
Sustainability and Gender in Engineering

Information Regarding Participation

We are interested in your experiences learning science. By filling out this questionnaire, you will help us find ways to improve science education for future students. Please make your best estimate for each item and answer as many questions as possible. There are no right or wrong answers; just do your best. Some questions will not apply to your experiences and can be left blank (e.g. questions about a course you have not taken). Please note:

- You must be 18 years or older to participate.
- The survey will take approximately 20 minutes to complete.
- Participation is voluntary. You may withdraw at any time.
- Participation will NOT impact your grade in this course in any way.
- You will be asked for contact information (email) in case we want to follow-up on some of your survey responses. This information is voluntary and will not be shared with any third party.
- If you have any questions or concerns, please contact Leidy Klotz (leidyk@clemson.edu), Geoff Potvin (gpotvin@clemson.edu), or Zahra Hazari (zahra@clemson.edu).
- You may contact the Clemson University Office of Research Compliance at 864-656-6460, toll-free at 866-297-3071, or irb@clemson.edu if you have any questions regarding your rights as research participants.

Enter your English course name/number on the line below.

Contact:
Leidy Klotz, Ph.D.
leidyk@clemson.edu

This project is funded by the National Science Foundation, grant number NSF 1036617.

11139
SECTION 1: YOUR CAREER GOALS

1. How important are the following factors for your future career satisfaction?

<table>
<thead>
<tr>
<th>Factor</th>
<th>Not at all important</th>
<th>Very important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Making money</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Becoming well known</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Helping others</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Supervising others</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Having job security and opportunity</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Working with people</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Inventing / designing things</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Developing new knowledge and skills</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Having lots of personal and family time</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Having an easy job</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Being in an exciting environment</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Solving societal problems</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Making use of my talents and abilities</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Doing hands-on work</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Applying math and science</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

2. Which BEST describes what you want(ed) to be in middle school, high school, and college? (Mark only ONE choice per column)

<table>
<thead>
<tr>
<th>Career Type</th>
<th>Middle school</th>
<th>Beginning of high school</th>
<th>End of high school</th>
<th>In college</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical professional (e.g. doctor, dentist, vet.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health professional (e.g. nursing, pharmacy)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental scientist</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemist</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physicist</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biologist</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer scientist/information technologist</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social scientist (e.g. sociologist, anthropologist)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other science-related career</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mathematician</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science/Math teacher</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other teacher</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other non-science related career</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Please rate the current likelihood of your choosing a career in the following:

<table>
<thead>
<tr>
<th>Career Type</th>
<th>Not at all likely</th>
<th>Extremely likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Science/Math teacher</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Environmental science</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Biology</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Physics</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Chemistry</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Bio-engineering</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Chemical engineering</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Materials engineering</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Civil engineering</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Industrial/Systems engineering</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Mechanical engineering</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Environmental engineering</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Electrical/computer engineering</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>
4. Which of these topics, if any, do you hope to directly address in your career? (Mark ALL that apply)

- [ ] Energy (supply or demand)
- [ ] Disease
- [ ] Poverty and distribution of wealth and resources
- [ ] Climate change
- [ ] Terrorism and war
- [ ] Water supply (e.g. shortages, pollution)
- [ ] Food availability
- [ ] Opportunities for future generations
- [ ] Opportunities for women and/or minorities
- [ ] Environmental degradation

SECTION 2: YOUR HIGH SCHOOL EXPERIENCES

5. What type of high school did you attend? (Mark ALL that apply)

- [ ] Private
- [ ] Public charter
- [ ] Magnet school
- [ ] Baccalaureate
- [ ] All male or female
- [ ] Private religious
- [ ] Vocational
- [ ] Home-schooled
- [ ] Foreign high school

6. How many students were in your high school biology, chemistry, and physics courses? (If you took multiple courses in a subject, please answer questions in this survey based on the LAST version of the course you took.)

   Biology:
   - 1–10
   - 11–20
   - 20–30
   - More than 30

   Chemistry:
   - 1–10
   - 11–20
   - 20–30
   - More than 30

   Physics:
   - 1–10
   - 11–20
   - 20–30
   - More than 30

7. Please estimate the distribution of males and females in your last high school biology, chemistry, and physics courses.

   All females       More females than males    About equal       More males than females    All males

   Biology:
   - [ ]
   - [ ]
   - [ ]
   - [ ]

   Chemistry:
   - [ ]
   - [ ]
   - [ ]
   - [ ]

   Physics:
   - [ ]
   - [ ]
   - [ ]
   - [ ]

8. In terms of learning the material, these courses required:

   Very little memorization
   - [ ]
   - [ ]
   - [ ]
   - [ ]
   A lot of memorization

   Biology:
   - [ ]
   - [ ]
   - [ ]
   - [ ]
   Chemistry:
   - [ ]
   - [ ]
   - [ ]
   - [ ]
   Physics:
   - [ ]
   - [ ]
   - [ ]
   - [ ]

9. In terms of learning the material, these courses required:

   Very little conceptual understanding
   - [ ]
   - [ ]
   - [ ]
   - [ ]
   A lot of conceptual understanding

   Biology:
   - [ ]
   - [ ]
   - [ ]
   - [ ]
   Chemistry:
   - [ ]
   - [ ]
   - [ ]
   - [ ]
   Physics:
   - [ ]
   - [ ]
   - [ ]
   - [ ]

10. Please indicate whether you did the following as part of your last high school science courses. (Mark ALL that apply)

   - Used the internet for blogging, twitter, or other social media
   - Watched science videos
   - Went on field trips
   - Participated in outdoor activities
   - Participated in debates, games, or contests
   - Kept an organized binder/notebook that the teacher checked periodically
   - Used clickers or other automated response systems
   - Completed online assignments
   - Used computer simulations or applets
   - Manipulated physical objects (e.g. used model kits)
   - Spoke with female engineer/scientist visitors
   - Spoke with male engineer/scientist visitors

Please continue to the next page
11. Please indicate how often the following occurred in your LAST high school science courses.

<table>
<thead>
<tr>
<th>Biology</th>
<th>Never</th>
<th>Rarely</th>
<th>Monthly</th>
<th>Weekly</th>
<th>Daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>The teacher lectured to the class</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>We spent time doing individual work in class</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Concepts/ideas were introduced before formulas/equations</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>We spent time doing small group activities</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>We worked on labs or projects</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Classmates taught each other</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Whole-class discussions were held</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>The teacher did demonstrations</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Topics were relevant to my life (e.g. chemistry at home, physics of sports)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>You asked questions, answered questions, or made comments</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Other students asked questions, answered questions, or made comments</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Teacher called on students for responses (not voluntary)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chemistry</th>
<th>Never</th>
<th>Rarely</th>
<th>Monthly</th>
<th>Weekly</th>
<th>Daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>The teacher lectured to the class</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>We spent time doing individual work in class</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Concepts/ideas were introduced before formulas/equations</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>We spent time doing small group activities</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>We worked on labs or projects</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Classmates taught each other</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Whole-class discussions were held</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>The teacher did demonstrations</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Topics were relevant to my life (e.g. chemistry at home, physics of sports)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>You asked questions, answered questions, or made comments</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Other students asked questions, answered questions, or made comments</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Teacher called on students for responses (not voluntary)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physics</th>
<th>Never</th>
<th>Rarely</th>
<th>Monthly</th>
<th>Weekly</th>
<th>Daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>The teacher lectured to the class</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>We spent time doing individual work in class</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Concepts/ideas were introduced before formulas/equations</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>We spent time doing small group activities</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>We worked on labs or projects</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Classmates taught each other</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Whole-class discussions were held</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>The teacher did demonstrations</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Topics were relevant to my life (e.g. chemistry at home, physics of sports)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>You asked questions, answered questions, or made comments</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Other students asked questions, answered questions, or made comments</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Teacher called on students for responses (not voluntary)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

12. Please indicate whether the following occurred in any projects or labs for these courses. *(Mark ALL that apply)*

<table>
<thead>
<tr>
<th>Biology</th>
<th>Chemistry</th>
<th>Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>I picked the topic</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I designed/built something</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I orally presented my work to the class</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>It addressed a community and/or family issue</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I integrated ideas and information from various sources</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Please continue to the next page
13. Please indicate whether the following topics were covered in your last high school courses. *(Mark ALL that apply)*

<table>
<thead>
<tr>
<th>Topic</th>
<th>Biology</th>
<th>Chemistry</th>
<th>Physics</th>
<th>Other Course(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy supply (e.g. fossil fuels, nuclear, solar, wind)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy demand (e.g. in buildings, transportation)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climate change</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terrorism &amp; war</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water supply (e.g. shortages, pollution, conflict)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population growth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food availability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disease</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poverty and distribution of wealth and resources</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sustainable development</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Life cycle analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomimicry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental degradation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Providing opportunities for future generations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work of female engineers/scientists</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Under-representation of females in engineering/science</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering careers, stages, or options</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benefits of becoming an engineer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Students' stories about engineering/science</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teachers' stories about their engineering/science experience</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

14. How many MINUTES did you spend doing work outside of class each day, on average, for your last high school science courses?

<table>
<thead>
<tr>
<th>Subject</th>
<th>0</th>
<th>5</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60 or more</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemistry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

15. Which, if any, of the following resources did you use during class in your LAST high school science courses? *(Mark ALL that apply)*

<table>
<thead>
<tr>
<th>Resource</th>
<th>Biology</th>
<th>Chemistry</th>
<th>Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphing calculator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project supplies/equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-textbook reading materials (e.g. newspapers, magazines)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

16. What types of questions were you required to answer in your last high school science courses? *(Mark ALL that apply)*

<table>
<thead>
<tr>
<th>Question</th>
<th>Biology</th>
<th>Chemistry</th>
<th>Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required several steps of calculations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required written explanations/essay responses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required graphing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required drawing or sketching</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Involved data presented in tables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Involved data analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required new insight and creativity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Had more than one correct response</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

17. How interested were most students in the content/topics in your last high school science course?

<table>
<thead>
<tr>
<th>Subject</th>
<th>Not at all interested</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Very Interested</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemistry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please continue to the next page
18. How would you rate your LAST high school BIOLOGY teacher on the following characteristics?

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Low 0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enthusiasm for biology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treated all students with respect</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explained ideas clearly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explained problems and answered questions in several different ways</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was able to organize lessons and classroom activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was able to handle discipline and manage the classroom</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was available to help students outside of class</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

19. How would you rate your LAST high school CHEMISTRY teacher on the following characteristics?

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Low 0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enthusiasm for chemistry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treated all students with respect</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explained ideas clearly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explained problems and answered questions in several different ways</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was able to organize lessons and classroom activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was able to handle discipline and manage the classroom</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was available to help students outside of class</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

20. How would you rate your LAST high school PHYSICS teacher on the following characteristics?

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Low 0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enthusiasm for physics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treated all students with respect</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explained ideas clearly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explained problems and answered questions in several different ways</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was able to organize lessons and classroom activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was able to handle discipline and manage the classroom</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was available to help students outside of class</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

21. How frequently have you done the following activities outside of formal courses?

<table>
<thead>
<tr>
<th>Activity</th>
<th>Never in my life</th>
<th>1–2 times</th>
<th>3–4 times</th>
<th>5–6 times</th>
<th>More than 6 times in my life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participated in engineering/ science clubs, camps, or competitions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tinkered with things (e.g. motors, mechanical devices)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Built things (e.g. structures, houses)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participated in other science/engineering hobbies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Read/watched science/engineering programs or literature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Read/watched science-fiction programs or literature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presented or gave a poster on science/engineering content</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explained science/engineering topics to experts (e.g. professionals, teachers)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explained science/engineering topics to non-experts (e.g. relatives, peers)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please continue to the next page
SECTION 3: SUSTAINABILITY AND YOU

When answering the following question, consider that the term sustainability is defined as “meeting the needs of the present without compromising the ability of future generations to meet their needs.”

22. To what extent do you disagree or agree with the following:

We can pursue sustainability without lowering our standard of living
0 1 2 3 4
Human ingenuity will ensure that we do not make the earth uninhabitable
0 1 2 3 4
I feel a responsibility to deal with environmental problems
0 1 2 3 4
Environmental problems make the future look hopeless
0 1 2 3 4
I can personally contribute to a sustainable future
0 1 2 3 4
Pursuit of sustainability will threaten jobs for people like me
0 1 2 3 4
Sustainable options typically cost more
0 1 2 3 4
Nothing I can do will make things better in other places on the planet
0 1 2 3 4
I have the knowledge to understand most sustainability issues
0 1 2 3 4
Climate change is caused by humans
0 1 2 3 4
I think of myself as part of nature, not separate from it
0 1 2 3 4
We should be taking stronger actions to address climate change
0 1 2 3 4

23. How likely are you to do the following:

Not at all likely
0 1 2 3 4
Extremely likely

Put on more clothes rather than turn up the heat when I’m cold
0 1 2 3 4
Use less water when taking a shower or bath
0 1 2 3 4
Evaluate the necessity of things I buy
0 1 2 3 4
Consider the energy/carbon/ecological impact of my food choices
0 1 2 3 4
Reuse bottles for water, coffee, or other drinks
0 1 2 3 4
Choose public transportation, carpool, bicycle or walk as a means of transportation
0 1 2 3 4
Buy a product because it is environmentally friendly
0 1 2 3 4
Take sustainability related courses in my area of academic interest
0 1 2 3 4
Contribute time or money to an environmental group
0 1 2 3 4
Educate others about the importance of these or similar actions
0 1 2 3 4

SECTION 4: ABOUT YOU

24. To what extent do you disagree or agree with the following:

I prefer to focus on details and leave the big picture to others
0 1 2 3 4
I hope to gain general knowledge across multiple fields
0 1 2 3 4
I often learn from my classmates
0 1 2 3 4
I prefer to focus on the big picture and leave the details to others
0 1 2 3 4
I hope to develop my expertise in one specific field
0 1 2 3 4
I identify relationships between topics from different courses
0 1 2 3 4
I analyze projects broadly to find a solution that will have the greatest impact
0 1 2 3 4
I seek input from those with a different perspective from me
0 1 2 3 4
I seek feedback and suggestions for personal improvement
0 1 2 3 4
When problem solving, I focus on the relationships between issues
0 1 2 3 4
I live in the moment
0 1 2 3 4
I plan ahead
0 1 2 3 4
When problem solving, I optimize each part of a project to produce the best result
0 1 2 3 4

Please continue to the next page
25. Please rate your general interest in the following areas.

<table>
<thead>
<tr>
<th>Understanding natural phenomena</th>
<th>Not at all interested</th>
<th>Very interested</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 1 2 3 4</td>
<td></td>
</tr>
<tr>
<td>Understanding science in everyday life</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explaining things with facts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telling others about science concepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Making scientific observations</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

26. How confident are you in your ability to do the following:

<table>
<thead>
<tr>
<th>Design an experiment to answer a scientific question</th>
<th>Not at all confident</th>
<th>Very confident</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 1 2 3 4</td>
<td></td>
</tr>
<tr>
<td>Conduct an experiment on your own</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interpret experimental results</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Write a lab report/scientific paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apply science knowledge to an assignment or test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explain a science topic to someone else</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Get good grades in science</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

27. To what extent do you disagree or agree with the following statements.

<table>
<thead>
<tr>
<th>PHYSICS</th>
<th>MATH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>Strongly disagree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>0 1 2 3 4</td>
<td>0 1 2 3 4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Statement</th>
<th>PHYSICS</th>
<th>MATH</th>
</tr>
</thead>
<tbody>
<tr>
<td>I see myself as a _______ person</td>
<td></td>
<td></td>
</tr>
<tr>
<td>My parents/relatives/friends see me as a _______ person</td>
<td></td>
<td></td>
</tr>
<tr>
<td>My _______ teacher sees me as a _______ person</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am interested in learning more about this subject</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am confident that I can understand this subject in class</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am confident that I can understand this subject outside of class</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I enjoy learning this subject</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I can do well on exams in this subject</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I understand concepts I have studied in this subject</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others ask me for help in this subject</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I wish I didn’t have to take this subject</td>
<td></td>
<td></td>
</tr>
<tr>
<td>This subject makes me nervous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I feel invisible in classes for this subject</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I can overcome setbacks in this subject</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

28. In your opinion, to what extent are the following associated with the field of engineering?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Very much so</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 1 2 3 4</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Statement</th>
<th>Not at all</th>
<th>Very much so</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creating economic growth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preserving national security</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improving quality of life</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saving lives</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caring for communities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protecting the environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Including women as participants in the field</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Including racial and ethnic minorities as participants in the field</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Addressing societal concerns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feeling a moral obligation to other people</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
29. To what extent do you disagree or agree with the following:

- Learning science will improve my career prospects
- Science is helpful in my everyday life
- Science has helped me see opportunities for positive change
- Science has taught me how to take care of my health
- Learning science has made me more critical in general
- Science and technology make our lives healthier, easier and more comfortable
- Technology is a solution to nearly all problems
- I use technology more than my peers
- Science and technology are the cause of most environmental problems
- A country needs science and technology to become developed
- The scientific method always leads to correct answers
- Scientists are completely neutral and objective
- Science and technology will provide greater opportunities for future generations
- The benefits of new technologies greatly outweigh the risks
- Science and technology are helping the poor
- We should trust what scientists have to say
- Scientific theories develop and change all the time

**Strongly disagree** 0 1 2 3 4 **Strongly agree**

30. How many college credit hours did you complete before starting college (e.g. AP credits, IB, dual credit)?

- 0
- 1–3
- 4–6
- 7–9
- 10–12
- 13–15
- >15

31. What was the highest level of education for your parents/guardians?

<table>
<thead>
<tr>
<th>Less than high school diploma</th>
<th>High school diploma/GED</th>
<th>Some college or associate/trade degree</th>
<th>Bachelor's degree</th>
<th>Master's degree or higher</th>
<th>Don't know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male parent/guardian</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female parent/guardian</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

32. Are any members of your family employed in the following professions? *(Mark ALL that apply)*

- Medical/health professional
- Scientist
- Engineer
- Teacher
- Other science, technology, or math related career
- Non-science related career

<table>
<thead>
<tr>
<th>Mother/female guardian</th>
<th>Father/male guardian</th>
<th>Siblings</th>
<th>Other relative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

33. Which of the following people have contributed to your selection of a career path? *(Mark ALL that apply)*

- Mother/female guardian
- Father/male guardian
- Siblings
- Other relative
- Coach
- Contact with someone in that major/career
- School counselor
- Math teacher
- Biology teacher
- Chemistry teacher
- Physics teacher
- Other teacher

34. Have you participated in Project Lead the Way?

- Yes
- No

Please continue to the next page
35. Which of the following statements describes your family’s interest in science and math? (Mark ALL that apply)

<table>
<thead>
<tr>
<th>Science</th>
<th>Math</th>
</tr>
</thead>
<tbody>
<tr>
<td>This topic was a diversion or hobby</td>
<td></td>
</tr>
<tr>
<td>This topic was a way for me to have a better career</td>
<td></td>
</tr>
<tr>
<td>My family helped me with my schoolwork in this topic</td>
<td></td>
</tr>
<tr>
<td>My family arranged for tutoring in this topic</td>
<td></td>
</tr>
<tr>
<td>This topic was a series of courses that I had to pass</td>
<td></td>
</tr>
<tr>
<td>This topic was not a family interest</td>
<td></td>
</tr>
</tbody>
</table>

36. Which of the following math courses did you take in high school? (Mark ALL that apply)

- Algebra I
- Algebra II
- Geometry
- Integrated Math
- Pre-Calculus
- Non-AP Calculus
- AP Calculus AB
- AP Calculus BC
- Statistics
- Trigonometry/Analytical Geometry

37. For each of the following standardized tests, please indicate the highest score you earned on that test.

SAT: _____ Total _____ Math _____ Critical Reading _____ Writing

ACT: _____ Total _____ Math _____ English _____ Science Reasoning _____ Reading

38. Please answer the following for the high school courses you took. Mark only ONE level, year, grade, and gender per row.

<table>
<thead>
<tr>
<th>HS course subject</th>
<th>Regular (R)</th>
<th>Honors (H)</th>
<th>AP</th>
<th>IB</th>
<th>Other (O)</th>
<th>Year taken HS</th>
<th>Final grade</th>
<th>Teacher gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Science</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental Science</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earth Science</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Biology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Biology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Chemistry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Chemistry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Physics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Physics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Math (most advanced)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>English (most advanced)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

39. For any AP exams you took, please indicate your test score.

<table>
<thead>
<tr>
<th>AP Exam</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP Calculus AB</td>
<td></td>
</tr>
<tr>
<td>AP Calculus BC</td>
<td></td>
</tr>
<tr>
<td>AP Biology</td>
<td></td>
</tr>
<tr>
<td>AP Chemistry</td>
<td></td>
</tr>
<tr>
<td>AP Physics B</td>
<td></td>
</tr>
<tr>
<td>AP Physics C</td>
<td></td>
</tr>
<tr>
<td>AP Environmental Science</td>
<td></td>
</tr>
</tbody>
</table>

Please continue to the next page
SECTION 5: DEMOGRAPHIC QUESTIONS

40. What is your gender?  ○ Female  ○ Male

41. With which racial group(s) do you identify? *(Mark ALL that apply)*
   ○ African-American or Black
   ○ South Asian (e.g. Indian, Pakistani, Bangladeshi, Sri Lankan, etc.)
   ○ Other Asian
   ○ American Indian or Alaskan Native
   ○ Caucasian or White
   ○ East Asian (e.g. Chinese, Korean, Japanese, etc.)
   ○ Native Hawaiian or Pacific Islander
   ○ Other

42. Please indicate if you are of Hispanic origin:  ○ Yes  ○ No

43. Which category best fits you and your parents’ or guardians’ background?

   Born in United States
   Me  ○ Yes  ○ No
   Male Parent or Guardian  ○ Yes  ○ No
   Female Parent or Guardian  ○ Yes  ○ No

44. Was English the primary spoken language in your household?  ○ Yes  ○ No

45. To help us estimate the size of the community you come from, please provide your home ZIP Code.

46. What year are you in college?  ○ 1st year  ○ 2nd year  ○ Other

47. We would like to contact the high school science teachers of some students participating in this
   survey (your teachers will not know your survey responses).
   Please provide the following for your most advanced high school science courses:

   Teacher’s Name:

   Biology  Chemistry

   Physics  Math

   Name of High School:

   City:  State:

We may contact some students to ask follow-up questions. All communications will be confidential and your email will NOT
be disclosed to any third party.

Your email address: ____________________________

Note: By completing this survey, you attest that you are 18 years of age or older and that you agree to participate in this research study.

You have reached the end of the survey.
Thank you for your time.
It is our goal that many science educators will benefit from the insights you have provided!
Appendix B  R Code for Chapter 3 Analyses

# Load libraries
library(car)
library(QuantPsyc)
library(Amelia)
library(Zelig)

## Load the SaGE data:
load("~/Desktop/Research/R Files/SaGEDatause.RData")

# Recode relevant variables
SaGE$Q24ar <- recode(SaGE$Q24a, '0=4;1=3;3=1;4=0')
SaGE$Q5ar <- recode(SaGE$Q5a, '1=1;else=0')
SaGE$Q5br <- recode(SaGE$Q5b, '1=1;else=0')
SaGE$Q5cr <- recode(SaGE$Q5c, '1=1;else=0')
SaGE$Q5dr <- recode(SaGE$Q5d, '1=1;else=0')
SaGE$Q5er <- recode(SaGE$Q5e, '1=1;else=0')
SaGE$Q5fr <- recode(SaGE$Q5f, '1=1;else=0')
SaGE$Q5gr <- recode(SaGE$Q5g, '1=1;else=0')
SaGE$Q5hr <- recode(SaGE$Q5h, '1=1;else=0')
SaGE$Q5ir <- recode(SaGE$Q5i, '1=1;else=0')
SaGE$Q5jr <- recode(SaGE$Q5j, '1=1;else=0')
SaGE$Q10Phys_ar <- recode(SaGE$Q10Phys_a, '1=1;else=0')
SaGE$Q10Phys_br <- recode(SaGE$Q10Phys_b, '1=1;else=0')
SaGE$Q10Phys_{cr} \leftarrow \text{recode}(\text{SaGE$Q10Phys_{c}},'1=1;\text{else}=0')$
SaGE$Q10Phys_{dr} \leftarrow \text{recode}(\text{SaGE$Q10Phys_{d}},'1=1;\text{else}=0')$
SaGE$Q10Phys_{er} \leftarrow \text{recode}(\text{SaGE$Q10Phys_{e}},'1=1;\text{else}=0')$
SaGE$Q10Phys_{fr} \leftarrow \text{recode}(\text{SaGE$Q10Phys_{f}},'1=1;\text{else}=0')$
SaGE$Q10Phys_{gr} \leftarrow \text{recode}(\text{SaGE$Q10Phys_{g}},'1=1;\text{else}=0')$
SaGE$Q10Phys_{hr} \leftarrow \text{recode}(\text{SaGE$Q10Phys_{h}},'1=1;\text{else}=0')$
SaGE$Q10Phys_{ir} \leftarrow \text{recode}(\text{SaGE$Q10Phys_{i}},'1=1;\text{else}=0')$
SaGE$Q10Phys_{jr} \leftarrow \text{recode}(\text{SaGE$Q10Phys_{j}},'1=1;\text{else}=0')$
SaGE$Q10Phys_{kr} \leftarrow \text{recode}(\text{SaGE$Q10Phys_{k}},'1=1;\text{else}=0')$
SaGE$Q10Phys_{lr} \leftarrow \text{recode}(\text{SaGE$Q10Phys_{l}},'1=1;\text{else}=0')$
SaGE$Q12Phys_{ar} \leftarrow \text{recode}(\text{SaGE$Q12Phys_{a}},'1=1;\text{else}=0')$
SaGE$Q12Phys_{br} \leftarrow \text{recode}(\text{SaGE$Q12Phys_{b}},'1=1;\text{else}=0')$
SaGE$Q12Phys_{cr} \leftarrow \text{recode}(\text{SaGE$Q12Phys_{c}},'1=1;\text{else}=0')$
SaGE$Q12Phys_{dr} \leftarrow \text{recode}(\text{SaGE$Q12Phys_{d}},'1=1;\text{else}=0')$
SaGE$Q12Phys_{er} \leftarrow \text{recode}(\text{SaGE$Q12Phys_{e}},'1=1;\text{else}=0')$
SaGE$Q13Phys_{ar} \leftarrow \text{recode}(\text{SaGE$Q13Phys_{a}},'1=1;\text{else}=0')$
SaGE$Q13Phys_{br} \leftarrow \text{recode}(\text{SaGE$Q13Phys_{b}},'1=1;\text{else}=0')$
SaGE$Q13Phys_{cr} \leftarrow \text{recode}(\text{SaGE$Q13Phys_{c}},'1=1;\text{else}=0')$
SaGE$Q13Phys_{dr} \leftarrow \text{recode}(\text{SaGE$Q13Phys_{d}},'1=1;\text{else}=0')$
SaGE$Q13Phys_{er} \leftarrow \text{recode}(\text{SaGE$Q13Phys_{e}},'1=1;\text{else}=0')$
SaGE$Q13Phys_{fr} \leftarrow \text{recode}(\text{SaGE$Q13Phys_{f}},'1=1;\text{else}=0')$
SaGE$Q13Phys_{gr} \leftarrow \text{recode}(\text{SaGE$Q13Phys_{g}},'1=1;\text{else}=0')$
SaGE$Q13Phys_{hr} \leftarrow \text{recode}(\text{SaGE$Q13Phys_{h}},'1=1;\text{else}=0')$
SaGE$Q13Phys_{ir} \leftarrow \text{recode}(\text{SaGE$Q13Phys_{i}},'1=1;\text{else}=0')$
SaGE$Q13Phys_{jr} \leftarrow \text{recode}(\text{SaGE$Q13Phys_{j}},'1=1;\text{else}=0')$
SaGE$Q13Phys_kr <- recode(SaGE$Q13Phys_k, '1=1; else=0')
SaGE$Q13Phys_lr <- recode(SaGE$Q13Phys_l, '1=1; else=0')
SaGE$Q13Phys_mr <- recode(SaGE$Q13Phys_m, '1=1; else=0')
SaGE$Q13Phys_nr <- recode(SaGE$Q13Phys_n, '1=1; else=0')
SaGE$Q13Phys_or <- recode(SaGE$Q13Phys_o, '1=1; else=0')
SaGE$Q13Phys_pr <- recode(SaGE$Q13Phys_p, '1=1; else=0')
SaGE$Q13Phys_qr <- recode(SaGE$Q13Phys_q, '1=1; else=0')
SaGE$Q13Phys_rr <- recode(SaGE$Q13Phys_r, '1=1; else=0')
SaGE$Q13Phys_sr <- recode(SaGE$Q13Phys_s, '1=1; else=0')
SaGE$Q13Phys_tr <- recode(SaGE$Q13Phys_t, '1=1; else=0')
SaGE$Q15Phys_ar <- recode(SaGE$Q15Phys_a, '1=1; else=0')
SaGE$Q15Phys_br <- recode(SaGE$Q15Phys_b, '1=1; else=0')
SaGE$Q15Phys_cr <- recode(SaGE$Q15Phys_c, '1=1; else=0')
SaGE$Q15Phys_dr <- recode(SaGE$Q15Phys_d, '1=1; else=0')
SaGE$Q16Phys_ar <- recode(SaGE$Q16Phys_a, '1=1; else=0')
SaGE$Q16Phys_br <- recode(SaGE$Q16Phys_b, '1=1; else=0')
SaGE$Q16Phys_cr <- recode(SaGE$Q16Phys_c, '1=1; else=0')
SaGE$Q16Phys_dr <- recode(SaGE$Q16Phys_d, '1=1; else=0')
SaGE$Q16Phys_er <- recode(SaGE$Q16Phys_e, '1=1; else=0')
SaGE$Q16Phys_fr <- recode(SaGE$Q16Phys_f, '1=1; else=0')
SaGE$Q16Phys_gr <- recode(SaGE$Q16Phys_g, '1=1; else=0')
SaGE$Q16Phys_hr <- recode(SaGE$Q16Phys_h, '1=1; else=0')
SaGE$Q32Mthr_ar <- recode(SaGE$Q32Mthr_a, '1=1; else=0')
SaGE$Q32Mthr_br <- recode(SaGE$Q32Mthr_b, '1=1; else=0')
SaGE$Q32Mthr_cr <- recode(SaGE$Q32Mthr_c, '1=1; else=0')
SaGE$Q32Mthr .dr ← recode (SaGE$Q32Mthr .d , '1=1; else=0')
SaGE$Q32Mthr .cr ← recode (SaGE$Q32Mthr .e , '1=1; else=0')
SaGE$Q32Mthr .fr ← recode (SaGE$Q32Mthr .f , '1=1; else=0')
SaGE$Q32Fthr .ar ← recode (SaGE$Q32Fthr .a , '1=1; else=0')
SaGE$Q32Fthr .br ← recode (SaGE$Q32Fthr .b , '1=1; else=0')
SaGE$Q32Fthr .cr ← recode (SaGE$Q32Fthr .c , '1=1; else=0')
SaGE$Q32Fthr .dr ← recode (SaGE$Q32Fthr .d , '1=1; else=0')
SaGE$Q32Fthr .er ← recode (SaGE$Q32Fthr .e , '1=1; else=0')
SaGE$Q32Fthr .fr ← recode (SaGE$Q32Fthr .f , '1=1; else=0')
SaGE$Q32Sib .ar ← recode (SaGE$Q32Sib .a , '1=1; else=0')
SaGE$Q32Sib .br ← recode (SaGE$Q32Sib .b , '1=1; else=0')
SaGE$Q32Sib .cr ← recode (SaGE$Q32Sib .c , '1=1; else=0')
SaGE$Q32Sib .dr ← recode (SaGE$Q32Sib .d , '1=1; else=0')
SaGE$Q32Sib .er ← recode (SaGE$Q32Sib .e , '1=1; else=0')
SaGE$Q32Sib .fr ← recode (SaGE$Q32Sib .f , '1=1; else=0')
SaGE$Q32Othr .ar ← recode (SaGE$Q32Othr .a , '1=1; else=0')
SaGE$Q32Othr .br ← recode (SaGE$Q32Othr .b , '1=1; else=0')
SaGE$Q32Othr .cr ← recode (SaGE$Q32Othr .c , '1=1; else=0')
SaGE$Q32Othr .dr ← recode (SaGE$Q32Othr .d , '1=1; else=0')
SaGE$Q32Othr .er ← recode (SaGE$Q32Othr .e , '1=1; else=0')
SaGE$Q32Othr .fr ← recode (SaGE$Q32Othr .f , '1=1; else=0')
SaGE$Q33ar ← recode (SaGE$Q33a , '1=1; else=0')
SaGE$Q33br ← recode (SaGE$Q33b , '1=1; else=0')
SaGE$Q33cr ← recode (SaGE$Q33c , '1=1; else=0')
SaGE$Q33dr ← recode (SaGE$Q33d , '1=1; else=0')
SaGE$Q33er <- recode(SaGE$Q33e, '1=1; else=0')
SaGE$Q33fr <- recode(SaGE$Q33f, '1=1; else=0')
SaGE$Q33gr <- recode(SaGE$Q33g, '1=1; else=0')
SaGE$Q33hr <- recode(SaGE$Q33h, '1=1; else=0')
SaGE$Q33ir <- recode(SaGE$Q33i, '1=1; else=0')
SaGE$Q33jr <- recode(SaGE$Q33j, '1=1; else=0')
SaGE$Q33kr <- recode(SaGE$Q33k, '1=1; else=0')
SaGE$Q33lr <- recode(SaGE$Q33l, '1=1; else=0')
SaGE$Q34r <- recode(SaGE$Q34, '2=1; else=0')
SaGE$Q35Sci_ar <- recode(SaGE$Q35Sci_a, '1=1; else=0')
SaGE$Q35Sci_br <- recode(SaGE$Q35Sci_b, '1=1; else=0')
SaGE$Q35Sci_cr <- recode(SaGE$Q35Sci_c, '1=1; else=0')
SaGE$Q35Sci_dr <- recode(SaGE$Q35Sci_d, '1=1; else=0')
SaGE$Q35Sci_er <- recode(SaGE$Q35Sci_e, '1=1; else=0')
SaGE$Q35Sci_fr <- recode(SaGE$Q35Sci_f, '1=1; else=0')
SaGE$Q35Sci_frev <- recode(SaGE$Q35Sci_f, '1=0; else=1')
SaGE$Q35Math_ar <- recode(SaGE$Q35Math_a, '1=1; else=0')
SaGE$Q35Math_br <- recode(SaGE$Q35Math_b, '1=1; else=0')
SaGE$Q35Math_cr <- recode(SaGE$Q35Math_c, '1=1; else=0')
SaGE$Q35Math_dr <- recode(SaGE$Q35Math_d, '1=1; else=0')
SaGE$Q35Math_er <- recode(SaGE$Q35Math_e, '1=1; else=0')
SaGE$Q35Math_fr <- recode(SaGE$Q35Math_f, '1=1; else=0')
SaGE$Black <- recode(SaGE$Q41a, '1=1; else=0')
SaGE$SAsian <- recode(SaGE$Q41b, '1=1; else=0')
SaGE$OAsian <- recode(SaGE$Q41c, '1=1; else=0')
SaGE$AmInd <- recode(SaGE$Q41d, '1=1; else=0')
SaGE$Cauc <- recode(SaGE$Q41e, '1=1; else=0')
SaGE$EAsian <- recode(SaGE$Q41f, '1=1; else=0')
SaGE$Hawaii <- recode(SaGE$Q41g, '1=1; else=0')
SaGE$Other <- recode(SaGE$Q41h, '1=1; else=0')
SaGE$Hisp <- SaGE$Q42
SaGE$Q38Grdhr <- recode(SaGE$Q38Grdh, '1=9;2=8;3=7;4=6;6=4;7=3;8=2;9=1')
SaGE$Q38Grdjr <- recode(SaGE$Q38Grdj, '1=9;2=8;3=7;4=6;6=4;7=3;8=2;9=1')

attach(SaGE)

## BUILD OTHER FACTORS

# Interdisciplinary Affinity
SaGE$IDA <- (Q24b+Q24f)/2

# Physics Identity Indicator
SaGE$PII <- (Q27Phys_b+Q27Phys_c+Q27Phys_d+Q27Phys_g)/4

# Math Identity Indicator
SaGE$MII <- (Q27Math_b+Q27Math_c+Q27Math_d+Q27Math_g)/4

# Teacher quality
SaGE$Teacher <- (Q20a+Q20b+Q20c+Q20d+Q20e+Q20f+Q20g)/7
# Mastery orientation

SaGE$Master <- (Q1g+Q1h+Q1o)

detach(SaGE)

# subset data with only physics grades reported

SaGEsub <- subset(SaGE, Q38Grdh>0 | Q38Grdi>0)
SaGEsub <- subset(SaGEsub, Q46=1)
Q16Phys_er" , "Q16Phys_fr" , "Q16Phys_gr" , "Q16Phys_hr" , "Q17Phys" , "Q21a" , "Q21b" , "Q21c" , "Q21d" , "Q21e" , "Q21f" , "Q21g" , "Q21h" , "Q21i" , "Q24a" , "Q24c" , "Q24d" , "Q24e" , "Q24g" , "Q24k" , "Q24l" , "Q25a" , "Q25b" , "Q25c" , "Q25d" , "Q25e" , "Q26a" , "Q26b" , "Q26c" , "Q26d" , "Q26e" , "Q26f" , "Q26g" , "Q29a" , "Q29b" , "Q29c" , "Q29d" , "Q29e" , "Q29f" , "Q29g" , "Q29i" , "Q29j" , "Q29k" , "Q29l" , "Q29m" , "Q29n" , "Q29o" , "Q29p" , "Q29q" , "Q30" , "Q31a" , "Q31b" , "Q32Mthr_ar" , "Q32Mthr_br" , "Q32Mthr_cr" , "Q32Mthr_hr" , "Q32Mthr_dr" , "Q32Fthr_ar" , "Q32Fthr_br" , "Q32Fthr_cr" , "Q32Fthr_hr" , "Q32Fthr_dr" , "Q33ar" , "Q33br" , "Q33cr" , "Q33dr" , "Q33er" , "Q33fr" , "Q33gr" , "Q33hr" , "Q33ir" , "Q33jr" , "Q33kr" , "Q33lr" , "Q35Sci_ar" , "Q35Sci_br" , "Q35Sci_cr" , "Q35Sci_dr" , "Q35Sci_hr" , "Q35Sci_ihr" , "Q35Sci_jhr" , "Q35Sci_khr" , "Q35Sci_lhr" , "Q35Math_ar" , "Q35Math_br" , "Q35Math_cr" , "Q35Math_dr" , "Q35Math_hr" , "Q35Math_ihr" , "Q35Math_jhr" , "Q35Math_khr" , "Q35Math_lhr" , "Q35Math_fr" , "Q34" , "Q38Lvlh" , "Q38Grdhr" , "Q38Grdjr" , "Q40" , "Black" , "SAsian" , "OAsian" , "AmInd" , "Cauc" , "EAsian" , "Hawaii" , "Other" , "Q42" , "Q43a" , "Q43b" , "Q43c" , "Q44" , "Q46" , "IDA" , "PII" , "MII" , "AIMath" , "AIEngl" , "AISci" , "Teacher" , "Master" ))

```r
# Multiple Imputation code

```

122
# recode Q31 to allow lm.beta to work

for (i in 1:5)
{
}
a.out$imputations [[ i ]] $Q31a ,”2=1; else=0”

a.out$imputations [[ i ]] $Q31b ,”2=1; else=0”

a.out$imputations [[ i ]] $Q31a ,”3=1; else=0”

a.out$imputations [[ i ]] $Q31b ,”3=1; else=0”

a.out$imputations [[ i ]] $Q31a ,”4=1; else=0”

a.out$imputations [[ i ]] $Q31b ,”4=1; else=0”

a.out$imputations [[ i ]] $Q31a ,”5=1; else=0”

a.out$imputations [[ i ]] $Q31b ,”5=1; else=0”

a.out$imputations [[ i ]] $Q31a ,”6=1; else=0”

a.out$imputations [[ i ]] $Q31b ,”6=1; else=0”

a.out$imputations [[ i ]] $Q11Phys ,”1=1; else=0”

a.out$imputations [[ i ]] $Q11Phys ,”2=1; else=0”

a.out$imputations [[ i ]] $Q11Phys ,”3=1; else=0”
[[i]] $Q11Phys_i = \begin{cases} 1; & \text{if } 3 \\
0; & \text{else} \end{cases}$

\begin{verbatim}
a.out$imputations[[i]]$Q11Phys_i4 <- recode(a.out$imputations[[i]]$Q11Phys_i, "4=1; else=0")
\end{verbatim}

```
#Correlations between physics and math identities and IA
cor(SaGEsub$PI, SaGEsub$IDA, use="complete")
cor.test(SaGEsub$PI, SaGEsub$IDA, use="complete")
cor(SaGEsub$MI, SaGEsub$IDA, use="complete")
cor.test(SaGEsub$MI, SaGEsub$IDA, use="complete")
```

```
## Physics Identity Model
summary(zelig(PII ~ IDA+Q24a+Q24d+Q24k+Q24l+Q24m+Q29a+Q29b+
Q29c+Q29d+Q29e+Q29f+Q29j+Q29k+Q29m+Q29n+Q29p+Q29q
  #Controls
  +as.factor(Q31a)+as.factor(Q31b)+Q17Phys+as.factor(Q32Mthr_br)+as.factor(Q32Fthr_br)+as.factor(Q35Sci_ar)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl+Q38Grdhr, data=a.out$imputations, model="ls")
)
```

```
##remove p>0.2
summary(zelig(PII ~ IDA+Q24l+Q29a+Q29b+Q29c+Q29d+Q29e+Q29k+
Q29m+Q29n
  #Controls
  +as.factor(Q31a)+as.factor(Q31b)+Q17Phys+as.factor(
```

125
Q32Mthr, Q32Fthr, Q35Sci, Q40, Cauc, AIMath, AISci, AIEngl, Q38Grdhr, data=a.out$imputations, model="ls")

#remove p>0.1
summary(zelig(PII \sim IDA+Q24l+Q29a+Q29c+Q29d+Q29e+Q29k+Q29m+Q29n
  #Controls
  +as.factor(Q31a)+as.factor(Q31b)+Q17Phys+as.factor(Q32Mthr, Q32Fthr, Q35Sci, Q40, Cauc, AIMath, AISci, AIEngl+Q38Grdhr, data=a.out$imputations, model="ls"))

#remove p>0.05
summary(zelig(PII ~ IDA+Q24l+Q29a+Q29c+Q29d+Q29e+Q29k+Q29m
  #Controls
  +as.factor(Q31a)+as.factor(Q31b)+Q17Phys+as.factor(Q32Mthr, Q32Fthr, Q35Sci, Q40, Cauc, AIMath, AISci, AIEngl+Q38Grdhr, data=a.out$imputations, model="ls"))

#remove p<0.01 (final version)
PIImodel<-zelig(PII ~ IDA+Q29a+Q29c+Q29k
  #Controls
  +as.factor(Q31a)+as.factor(Q31b)+Q17Phys+as.factor(Q32Mthr, Q32Fthr, Q35Sci, Q40, Cauc, AIMath, AISci, AIEngl+Q38Grdhr, data=a.out$imputations, model="ls"))
Q38Grdhr, data=a.out$imputations, model="ls")

summary(PImodel)

print(summary(PImodel), subset=1:5)

# Calculation of standard coefficients and R^2
PIfirst<-lm.beta(lm(PII ~ IDA+Q29a+Q29c+Q29k+as.factor(Q31a_2)+as.factor(Q31b_2)+as.factor(Q31a_3)+as.factor(Q31b_3)+as.factor(Q31a_4)+as.factor(Q31b_4)+as.factor(Q31a_5)+as.factor(Q31b_5)+as.factor(Q31a_6)+as.factor(Q31b_6)+Q17Phys+as.factor(Q32Mthr_br)+as.factor(Q32Fthr_br)+as.factor(Q35Sci_ar)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEL)+Q38Grdhr, data=a.out$imputations[[1]])

PIsecond<-lm.beta(lm(PII ~ IDA+Q29a+Q29c+Q29k+as.factor(Q31a_2)+as.factor(Q31b_2)+as.factor(Q31a_3)+as.factor(Q31b_3)+as.factor(Q31a_4)+as.factor(Q31b_4)+as.factor(Q31a_5)+as.factor(Q31b_5)+as.factor(Q31a_6)+as.factor(Q31b_6)+Q17Phys+as.factor(Q32Mthr_br)+as.factor(Q32Fthr_br)+as.factor(Q35Sci_ar)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+ AIEL)+Q38Grdhr, data=a.out$imputations[[2]])

PIthird<-lm.beta(lm(PII ~ IDA+Q29a+Q29c+Q29k+as.factor(Q31a_2)+as.factor(Q31b_2)+as.factor(Q31a_3)+as.factor(Q31b_3)+as.factor(Q31a_4)+as.factor(Q31b_4)+as.factor(Q31a_5)+as.factor(Q31b_5)+as.factor(Q31a_6)+as.factor(Q31b_6)+Q17Phys+as.factor(Q32Mthr_br)+as.factor(Q32Fthr_br)+as.factor(Q35Sci_ar)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEL)+Q38Grdhr, data=a.out$imputations[[3]])
AIEngl+Q38Grdhr, data=a.out$imputations[[3]])

PIfourth<-lm.beta(lm(PII ~ IDA+Q29a+Q29c+Q29k+as.factor(Q31a_2)+as.factor(Q31b_2)+as.factor(Q31a_3)+as.factor(Q31b_3)+as.factor(Q31a_4)+as.factor(Q31b_4)+as.factor(Q31a_5)+as.factor(Q31b_5)+as.factor(Q31a_6)+as.factor(Q31b_6)+Q17Phys+as.factor(Q32Mthr_br)+as.factor(Q32Fthr_br)+as.factor(Q35Sci_ar)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl+Q38Grdhr, data=a.out$imputations[[4]])

PIfifth<-lm.beta(lm(PII ~ IDA+Q29a+Q29c+Q29k+as.factor(Q31a_2)+as.factor(Q31b_2)+as.factor(Q31a_3)+as.factor(Q31b_3)+as.factor(Q31a_4)+as.factor(Q31b_4)+as.factor(Q31a_5)+as.factor(Q31b_5)+as.factor(Q31a_6)+as.factor(Q31b_6)+Q17Phys+as.factor(Q32Mthr_br)+as.factor(Q32Fthr_br)+as.factor(Q35Sci_ar)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl+Q38Grdhr, data=a.out$imputations[[5]])

PIBetas=NULL
for (i in 1:24)
{
  PIBetas[i]<-mean(c(PIfirst[i], PIsecond[i], PIthird[i],
                     PIfourth[i], PIfifth[i]))
}

## Math identity model
summary(zelig(MII ~ IDA+Q24a+Q24d+Q24e+Q24k+Q24l+Q29a+Q29b+...
Q29c+Q29d+Q29f+Q29j+Q29k+Q29m+Q29n

# Controls
+as.factor(Q31a)+as.factor(Q31b)+as.factor(Q32Mthr_br)+as.factor(Q32Fthr_br)+as.factor(Q35Math_ar)
+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl+Q38Grdjr, data=a.out$imputations, model="ls")

# 2nd iteration (remove p > 0.2)
summary(zelig(MII ~ IDA+Q24a+Q24d+Q24l+Q29a+Q29b+Q29c+Q29d+Q29m)

# Controls
+as.factor(Q31a)+as.factor(Q31b)+as.factor(Q32Mthr_br)+as.factor(Q32Fthr_br)+as.factor(Q35Math_ar)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl+Q38Grdjr, data=a.out$imputations, model="ls")

# 3rd iteration (remove p > 0.1)
summary(zelig(MII ~ Q24a+Q24d+Q24l+Q29a+Q29b+Q29d+Q29m)

# Controls
+as.factor(Q31a)+as.factor(Q31b)+as.factor(Q32Mthr_br)+as.factor(Q32Fthr_br)+as.factor(Q35Math_ar)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl+Q38Grdjr, data=a.out$imputations, model="ls")

# 4th iteration (remove p > 0.05)
summary(zelig(MII ~ Q24a+Q24d+Q29a+Q29m+Q29d)

# Controls
+as.factor(Q31a)+as.factor(Q31b)+as.factor(Q32Mthr_br)+as
\begin{verbatim}
  factor(Q32Fthr_br)+factor(Q35Math_ar)+factor(Q40)+factor(Cauc)+AIMath+AIEngl+Q38Grdjr, data =a.out$imputations, model="ls" }

#5th iteration (remove p>0.01)
MImodel<zelig(MII ~ Q24a+Q24l+Q29a+Q29b+Q29d+Q29m
  #Controls
  +factor(Q31a)+factor(Q31b)+factor(Q32Mthr_br)+factor(Q32Fthr_br)+factor(Q35Math_ar)+factor(Q40)+factor(Cauc)+AIMath+AIEngl+Q38Grdjr, data =a.out$imputations, model="ls")

summary(MImodel)
print(summary(MImodel),subset=1:5)

#This produces standardized coefficients for each imputation.
These are averaged to give results
#published in the tables.
MIfirst<-lm.beta(lm(MII ~ Q24a+Q24l+Q29a+Q29b+Q29d+Q29m+factor(Q31a_2)+factor(Q31a_3)+factor(Q31a_4)+factor(Q31a_5)+factor(Q31a_6)+factor(Q31b_2)+factor(Q31b_3)+factor(Q31b_4)+factor(Q31b_5)+factor(Q31b_6)+factor(Q32Mthr_br)+factor(Q32Fthr_br)+factor(Q35Math_ar)+factor(Q40)+factor(Cauc)+AIMath+AIEngl+Q38Grdjr, data=a.out$imputations[[1]]))
MIsecond<-lm.beta(lm(MII ~ Q24a+Q24l+Q29a+Q29b+Q29d+Q29m+factor(Q31a_2)+factor(Q31a_3)+factor(Q31a_4)+as.factor(Q31a_5)+as.factor(Q31a_6)+as.factor(Q31b_2)+as.factor(Q31b_3)+as.factor(Q31b_4)+as.factor(Q31b_5)+as.factor(Q31b_6)+as.factor(Q32Mthr_br)+as.factor(Q32Fthr_br)+as.factor(Q35Math_ar)+as.factor(Q40)+as.factor(Cauc)+AIMath+AIEngl+Q38Grdjr, data=a.out$imputations[[1]]))
\end{verbatim}
factor(Q31a_5) + as.factor(Q31a_6) + as.factor(Q31b_2) + as.factor(Q31b_3) + as.factor(Q31b_4) + as.factor(Q31b_5) + as.factor(Q31b_6) + as.factor(Q32Mthr_br) + as.factor(Q32Fthr_br) + as.factor(Q35Math_ar) + as.factor(Q40) + as.factor(Cauc) + AIMath + AISci + AIEngl + Q38Grdjr, data = a.out$imputations[[2]])

Mi third <- lm.beta(lm(MII ~ Q24a + Q24l + Q29a + Q29b + Q29d + Q29m + as.factor(Q31a_2) + as.factor(Q31a_3) + as.factor(Q31a_4) + as.factor(Q31b_2) + as.factor(Q31b_3) + as.factor(Q31b_4) + as.factor(Q31b_5) + as.factor(Q31b_6) + as.factor(Q32Mthr_br) + as.factor(Q32Fthr_br) + as.factor(Q35Math_ar) + as.factor(Q40) + as.factor(Cauc) + AIMath + AISci + AIEngl + Q38Grdjr, data = a.out$imputations[[3]])

Mi fourth <- lm.beta(lm(MII ~ Q24a + Q24l + Q29a + Q29b + Q29d + Q29m + as.factor(Q31a_2) + as.factor(Q31a_3) + as.factor(Q31a_4) + as.factor(Q31b_2) + as.factor(Q31b_3) + as.factor(Q31b_4) + as.factor(Q31b_5) + as.factor(Q31b_6) + as.factor(Q32Mthr_br) + as.factor(Q32Fthr_br) + as.factor(Q35Math_ar) + as.factor(Q40) + as.factor(Cauc) + AIMath + AISci + AIEngl + Q38Grdjr, data = a.out$imputations[[4]])

Mi fifth <- lm.beta(lm(MII ~ Q24a + Q24l + Q29a + Q29b + Q29d + Q29m + as.factor(Q31a_2) + as.factor(Q31a_3) + as.factor(Q31a_4) + as.factor(Q31b_2) + as.factor(Q31b_3) + as.factor(Q31b_4) + as.factor(Q31b_5) + as.factor(Q31b_6) + as.factor(Q32Mthr_br) + as.factor(Q32Fthr_br) + as.factor(Q35Math_ar) + as.factor(Q40) + as.factor(Cauc) +
AIMath+AISci+AIEngl+Q38Grdjr, data=a.out$imputations[[5]])

MIBetas=NULL

for (i in 1:25)
{
  MIBetas[i]<-mean(c(MIfirst[i], MIsecond[i], MIthird[i],
                   MIfourth[i], MIfifth[i]))
}

## These models are to determine which of Q24 and Q29 are
## interacting with IDA
#With IDA added: p=0.13
summary(zelig(MII ~ IDA+Q24a+Q24l+Q29a+Q29b+Q29d+Q29m
   #Controls
   +Q31a+Q31b+Q32Mthr_br+Q32Fthr_br+Q35Math_ar+Q40+Cauc+
   AIMath+AISci+AIEngl+Q38Grdjr, data=a.out$imputations,
   model="ls" ))
#with Q24a removed: IDA p=0.07
summary(zelig(MII ~ IDA+Q24l+Q29a+Q29b+Q29d+Q29m
   #Controls
   +Q31a+Q31b+Q32Mthr_br+Q32Fthr_br+Q35Math_ar+Q40+Cauc+
   AIMath+AISci+AIEngl+Q38Grdjr, data=a.out$imputations,
   model="ls" ))
#with Q24l removed: IDA p=0.03
summary(zelig(MII ~ IDA+Q24a+Q29a+Q29b+Q29d+Q29m
   #Controls
   +Q31a+Q31b+Q32Mthr_br+Q32Fthr_br+Q35Math_ar+Q40+Cauc+
   AIMath+AISci+AIEngl+Q38Grdjr, data=a.out$imputations,
   model="ls" ))
# Controls

+Q31a+Q31b+Q32Mthr.br+Q32Fthr.br+Q35Math.ar+Q40+Cauc+
  AIMath+AISci+AIEngl+Q38Grdjr , data=a.out$imputations,
  model="ls")

# with Q29a removed: IDA p=0.11

summary(zelig(MII ~ IDA+Q24a+Q24l+Q29b+Q29d+Q29m
  # Controls
  +Q31a+Q31b+Q32Mthr.br+Q32Fthr.br+Q35Math.ar+Q40+Cauc+
  AIMath+AISci+AIEngl+Q38Grdjr , data=a.out$imputations,
  model="ls")

# with Q29b removed: IDA p=0.06

summary(zelig(MII ~ IDA+Q24a+Q24l+Q29a+Q29d+Q29m
  # Controls
  +Q31a+Q31b+Q32Mthr.br+Q32Fthr.br+Q35Math.ar+Q40+Cauc+
  AIMath+AISci+AIEngl+Q38Grdjr , data=a.out$imputations,
  model="ls")

# with Q29d removed: IDA p=0.18

summary(zelig(MII ~ IDA+Q24a+Q24l+Q29a+Q29b+Q29m
  # Controls
  +Q31a+Q31b+Q32Mthr.br+Q32Fthr.br+Q35Math.ar+Q40+Cauc+
  AIMath+AISci+AIEngl+Q38Grdjr , data=a.out$imputations,
  model="ls")

# with Q29m removed: IDA p=0.05

summary(zelig(MII ~ IDA+Q24a+Q24l+Q29a+Q29b+Q29d
  # Controls
+Q31a+Q31b+Q32Mthr_br+Q32Fthr_br+Q35Math_ar+Q40+Cauc+
AIMath+AISci+AIEngl+Q38Grdjr, data=a.out$imputations,
model="ls")

## Model predicting IDA
summary(zelig(IDA ~
  # Background/controls
  as.factor(Q31a)+as.factor(Q31b)+as.factor(Q40)+as.
  factor(Cauc)+AIMath+AISci+AIEngl
  # Pedagogies
  +as.factor(Q11Phys_a)+as.factor(Q11Phys_b)+as.factor(
    Q11Phys_c)+as.factor(Q11Phys_d)+as.factor(Q11Phys_e)
  +as.factor(Q11Phys_f)+as.factor(Q11Phys_g)+as.factor
    (Q11Phys_h)+as.factor(Q11Phys_i)+as.factor(Q11Phys_l)
  # Activities
  +as.factor(Q10Phys_br)+as.factor(Q10Phys_cr)+as.factor(
    Q10Phys_dr)+as.factor(Q10Phys_er)+as.factor(Q12Phys_ar)
  +as.factor(Q12Phys_br)+as.factor(Q12Phys_cr)+as.
    factor(Q12Phys_dr)+as.factor(Q12Phys_er)
  # Assessments
  +Q8Phys+Q9Phys+as.factor(Q10Phys_fr)+as.factor(Q10Phys_gr)
  +as.factor(Q10Phys_hr)+as.factor(Q16Phys_ar)+as.
    factor(Q16Phys_br)+as.factor(Q16Phys_cr)+as.factor(
    Q16Phys_dr)+as.factor(Q16Phys_er)+as.factor(Q16Phys_
fr) + as.factor(Q16Phys_gr) + as.factor(Q16Phys_hr)

# Syntax
, data = a.out$imputations, model = "ls")

# remove p > 0.2 from previous model

summary(zelig(IDA ~

# Background/controls
as.factor(Q31a) + as.factor(Q31b) + as.factor(Q40) + as.factor(Cauc) + AIMath + AISci + AIEngl

# Pedagogies
+ as.factor(Q11Phys_b) + as.factor(Q11Phys_c) + as.factor(Q11Phys_d) + as.factor(Q11Phys_e) + as.factor(Q11Phys_f)
+ as.factor(Q11Phys_i)

# Activities
+ as.factor(Q10Phys_br) + as.factor(Q10Phys_cr) + as.factor(Q10Phys_dr)

# Assessments
+ Q9Phys + as.factor(Q10Phys_gr) + as.factor(Q16Phys_ar) + as.factor(Q16Phys_fr) + as.factor(Q16Phys_gr)

# Syntax
, data = a.out$imputations, model = "ls")

# remove p > 0.1 from previous model

summary(zelig(IDA ~

# Background/controls
as.factor(Q31a) + as.factor(Q31b) + as.factor(Q40) + as.factor(Cauc) + AIMath + AISci + AIEngl

135
# Pedagogies
+as.factor(Q11Phys_b)+as.factor(Q11Phys_c)+as.factor(Q11Phys_d)+as.factor(Q11Phys_e)+as.factor(Q11Phys_f)+as.factor(Q11Phys_i)

# Activities
+as.factor(Q10Phys_cr)

# Assessments
+Q9Phys+as.factor(Q10Phys_gr)+as.factor(Q16Phys_ar)+as.factor(Q16Phys_fr)

# Syntax
, data=a.out$imputations, model="ls")

# remove p > 0.05 from previous model
summary(zelig(IDA ~

# Background/controls
as.factor(Q31a)+as.factor(Q31b)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl

# Pedagogies
+as.factor(Q11Phys_b)+as.factor(Q11Phys_d)+as.factor(Q11Phys_f)+as.factor(Q11Phys_i)

# Activities
+as.factor(Q10Phys_cr)

# Assessments
+Q9Phys+as.factor(Q10Phys_gr)+as.factor(Q16Phys_ar)+as.factor(Q16Phys_fr)

# Syntax
#remove p>0.01 from previous model

IAmodel <- zelig(IDA ~

#Background/controls
as.factor(Q31a)+as.factor(Q31b)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl

#Pedagogies
+as.factor(Q11Phys_i)

#Activities
#Assessments
+Q9Phys+as.factor(Q16Phys_ar)

#Syntax
, data=a.out$imputations, model="ls"

summary(IAmodel)

print(summary(IAmodel), subset = 1:5)

#Code to obtain betas for the IA model

IAfirst <- lm.beta(lm(IDA ~ as.factor(Q31a_2)+as.factor(Q31a_3)+as.factor(Q31a_4)+as.factor(Q31a_5)+as.factor(Q31a_6)+as.factor(Q31b_2)+as.factor(Q31b_3)+as.factor(Q31b_4)+as.factor(Q31b_5)+as.factor(Q31b_6)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl+as.factor(Q11Phys_i1)+as.factor(Q11Phys_i2)+as.factor(Q11Phys_i3)+as.factor(Q11Phys_i4)+Q9Phys+as.factor(Q16Phys_ar), data=a.out$imputations[[1]])

IAssecond <- lm.beta(lm(IDA ~ as.factor(Q31a_2)+as.factor(Q31a_3)+as.factor(Q31a_4)+as.factor(Q31a_5)+as.factor(Q31a_6)+as.factor(Q31b_2)+as.factor(Q31b_3)+as.factor(Q31b_4)+as.factor(Q31b_5)+as.factor(Q31b_6)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl+as.factor(Q11Phys_i1)+as.factor(Q11Phys_i2)+as.factor(Q11Phys_i3)+as.factor(Q11Phys_i4)+Q9Phys+as.factor(Q16Phys_ar), data=a.out$imputations[[1]])
as.factor(Q31a_4)+as.factor(Q31a_5)+as.factor(Q31a_6)+as.factor(Q31b_2)+as.factor(Q31b_3)+as.factor(Q31b_4)+as.factor(Q31b_5)+as.factor(Q31b_6)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl+as.factor(Q11Phys_i1)+as.factor(Q11Phys_i2)+as.factor(Q11Phys_i3)+as.factor(Q11Phys_i4)+Q9Phys+as.factor(Q16Phys_ar), data=a.out$imputations[[2]])
IAthird<-lm.beta(lm(IDA~as.factor(Q31a_2)+as.factor(Q31a_3)+as.factor(Q31a_4)+as.factor(Q31a_5)+as.factor(Q31a_6)+as.factor(Q31b_2)+as.factor(Q31b_3)+as.factor(Q31b_4)+as.factor(Q31b_5)+as.factor(Q31b_6)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl+as.factor(Q11Phys_i1)+as.factor(Q11Phys_i2)+as.factor(Q11Phys_i3)+as.factor(Q11Phys_i4)+Q9Phys+as.factor(Q16Phys_ar), data=a.out$imputations[[3]])
IAfourth<-lm.beta(lm(IDA~as.factor(Q31a_2)+as.factor(Q31a_3)+as.factor(Q31a_4)+as.factor(Q31a_5)+as.factor(Q31a_6)+as.factor(Q31b_2)+as.factor(Q31b_3)+as.factor(Q31b_4)+as.factor(Q31b_5)+as.factor(Q31b_6)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl+as.factor(Q11Phys_i1)+as.factor(Q11Phys_i2)+as.factor(Q11Phys_i3)+as.factor(Q11Phys_i4)+Q9Phys+as.factor(Q16Phys_ar), data=a.out$imputations[[4]])
IAfifth<-lm.beta(lm(IDA~as.factor(Q31a_2)+as.factor(Q31a_3)+as.factor(Q31a_4)+as.factor(Q31a_5)+as.factor(Q31a_6)+as.factor(Q31b_2)+as.factor(Q31b_3)+as.factor(Q31b_4)+as.factor(Q31b_5)+as.factor(Q31b_6)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl+as.factor(Q11Phys_i1)+as.factor(Q11Phys_i2)+as.factor(Q11Phys_i3)+as.factor(Q11Phys_i4)+Q9Phys+as.factor(Q16Phys_ar), data=a.out$imputations[[5]])
Q11Phys_i2 + as.factor(Q11Phys_i3) + as.factor(Q11Phys_i4) + Q9Phys + as.factor(Q16Phys_ar), data=a.out$imputations[[5]])

IABetas=NULL

for (i in 1:21)
{
  IABetas[i] <- mean(c(IAfirst[i], IAsecond[i], IAthird[i],
                      IAFourth[i], IAFifth[i]))
}

# Adding Mastery orientation to IDA model (reported in Section 4.3)

summary(zelig(IDA ~
             # Background/controls
             as.factor(Q31a) + as.factor(Q31b) + as.factor(Q40) + as.factor(Cauc) + AIMath + AISci + AIEngl + Master
             # Pedagogies
             + as.factor(Q11Phys_b) + as.factor(Q11Phys_d) + as.factor(Q11Phys_f) + as.factor(Q11Phys_i)
             # Activities
             + as.factor(Q10Phys_cr)
             # Assessments
             + Q9Phys + as.factor(Q10Phys_gr) + as.factor(Q16Phys_ar) + as.factor(Q16Phys_fr)
             # Syntax

139
```r
# remove p > 0.05
summary(zelig(IDA ~
  # Background/controls
  as.factor(Q31a)+as.factor(Q31b)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl+Master
  # Pedagogies
  +as.factor(Q11Phys_d)+as.factor(Q11Phys_f)+as.factor(Q11Phys_i)
  # Activities
  # Assessments
  +Q9Phys+as.factor(Q10Phys_gr)+as.factor(Q16Phys_ar)+as.factor(Q16Phys_fr)
  # Syntax
  , data=a.out$imputations , model="ls" )
# remove p > 0.01
summary(zelig(IDA ~
  # Background/controls
  as.factor(Q31a)+as.factor(Q31b)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl+Master
  # Pedagogies
  +as.factor(Q11Phys_f)+as.factor(Q11Phys_i)
  # Activities
  # Assessments
  +Q9Phys+as.factor(Q10Phys_gr)+as.factor(Q16Phys_ar)
```

140
# Syntax

```r
.data = a.out$imputations, model="ls")
```

# remove p > 0.01

```r
WithMastery <- zelig(IDA ~
# Background/controls
  as.factor(Q31a)+as.factor(Q31b)+as.factor(Q40)+as.factor(Cauc)+AIMath+AISci+AIEngl+Master
# Pedagogies
  +as.factor(Q11Phys_i)
# Activities
# Assessments
  +Q9Phys+as.factor(Q16Phys_ar)
# Syntax
  , data = a.out$imputations, model="ls")
```

```r
summary(WithMastery)
```

```r
print(summary(WithMastery), subset = 1:5)
```

# Code to obtain betas for the IA model with mastery

```r
IAMfirst <- lm.beta(lm(IDA ~ as.factor(Q31a_2)+as.factor(Q31a_3)+
  as.factor(Q31a_4)+as.factor(Q31a_5)+as.factor(Q31a_6)+as.
  factor(Q31b_2)+as.factor(Q31b_3)+as.factor(Q31b_4)+as.
  factor(Q31b_5)+as.factor(Q31b_6)+as.factor(Q40)+as.factor(
  Cauc)+AIMath+AISci+AIEngl+Master+as.factor(Q11Phys_i1)+as.
  factor(Q11Phys_i2)+as.factor(Q11Phys_i3)+as.factor(Q11Phys
  _i4)+Q9Phys+as.factor(Q16Phys_ar), data = a.out$imputations
```

141
IAMsecond <- lm.beta(lm(IDA^ as.factor(Q31a_2) + as.factor(Q31a_3) + as.factor(Q31a_4) + as.factor(Q31a_5) + as.factor(Q31a_6) + as.factor(Q31b_2) + as.factor(Q31b_3) + as.factor(Q31b_4) + as.factor(Q31b_5) + as.factor(Q31b_6) + as.factor(Q40) + as.factor(Cauc) + AIMath + AISci + AIEngl + Master + as.factor(Q11Phys_i1) + as.factor(Q11Phys_i2) + as.factor(Q11Phys_i3) + as.factor(Q11Phys_i4) + Q9Phys + as.factor(Q16Phys_ar), data = a.out$imputations[[2]]))
IAMthird <- lm.beta(lm(IDA^ as.factor(Q31a_2) + as.factor(Q31a_3) + as.factor(Q31a_4) + as.factor(Q31a_5) + as.factor(Q31a_6) + as.factor(Q31b_2) + as.factor(Q31b_3) + as.factor(Q31b_4) + as.factor(Q31b_5) + as.factor(Q31b_6) + as.factor(Q40) + as.factor(Cauc) + AIMath + AISci + AIEngl + Master + as.factor(Q11Phys_i1) + as.factor(Q11Phys_i2) + as.factor(Q11Phys_i3) + as.factor(Q11Phys_i4) + Q9Phys + as.factor(Q16Phys_ar), data = a.out$imputations[[3]]))
IAMfourth <- lm.beta(lm(IDA^ as.factor(Q31a_2) + as.factor(Q31a_3) + as.factor(Q31a_4) + as.factor(Q31a_5) + as.factor(Q31a_6) + as.factor(Q31b_2) + as.factor(Q31b_3) + as.factor(Q31b_4) + as.factor(Q31b_5) + as.factor(Q31b_6) + as.factor(Q40) + as.factor(Cauc) + AIMath + AISci + AIEngl + Master + as.factor(Q11Phys_i1) + as.factor(Q11Phys_i2) + as.factor(Q11Phys_i3) + as.factor(Q11Phys_i4) + Q9Phys + as.factor(Q16Phys_ar), data = a.out$imputations[[4]]))

142
IAMfifth <- lm.beta(lm(IDA ~ as.factor(Q31a_2) + as.factor(Q31a_3) + as.factor(Q31a_4) + as.factor(Q31a_5) + as.factor(Q31a_6) + as.factor(Q31b_2) + as.factor(Q31b_3) + as.factor(Q31b_4) + as.factor(Q31b_5) + as.factor(Q31b_6) + as.factor(Q40) + as.factor(Cauc) + AIMath + AISci + AIEngl + Master + as.factor(Q11Phys_i1) + as.factor(Q11Phys_i2) + as.factor(Q11Phys_i3) + as.factor(Q11Phys_i4) + Q9Phys + as.factor(Q16Phys_ar), data=a.out$imputations[[5]]))

IAMBetas = NULL
for (i in 1:22)
{
  IAMBetas[i] <- mean(c(IAMfirst[i], IAMsecond[i], IAMthird[i], IAMfourth[i], IAMfifth[i]))
}
Appendix C  Interview protocol for school site visit

Questions:

Class

What did you think about class today?
What about class do you enjoy?
Think about your favorite day in this class. Tell me about what happened during that day.
Think about one of your least favorite class days. Tell me about that.
What topics from the class interest you most? Why?
Do you talk about this class outside of class time?
Do you help other students in this class?
Have you ever looked up additional information outside of class?
How does this teacher compare to your other teachers?
Is the culture of your school a good fit with the culture of science (physics)?

Career Plans

What are your current plans for your career? How did you decide on that?
What other careers have you thought about? (looking for possible non-engineers)
Do you have a specific discipline in mind? (if indicated that they are interested in engineering)
Who encourages you toward your career goals?
Did any topics you discussed in class affect your career plans?

Sustainability

Do you know what the word sustainability means? Can you explain it to me?

Ask specifically about topics related to sustainability (if students brought it up)?
How did your teacher cover these topics (lecture, activities, etc)?

Were these methods helpful to your learning?

Do you see yourself as a sustainable/green person?

Do you take any actions to be a green/er person? (recycle, conserve water, energy..)

How often do you do these things? Any particular reason why you do (these things)?

Is it an intentional effort?

Identity

What does it mean to be a science person?

Could anyone be a science person?

Are you a science person?

What does it mean to be a math person?

Reword if necessary...what are the characteristics of a math person

Could anyone be a math person?

Are you a math person?

What does it mean to be a physics person?

Could anyone be a physics person?

Are you a physics person?

Do physics people have other interests?

Do you have other interests?

Do your friends like physics? Think physics is cool? Think less of you for taking physics? Care about their grades?

Do most students in your school like physics? Think physics is cool? Think less of you for taking physics? Care about their grades?

What is engineering?

What do engineers do?

What could you do with a career in engineering?
Who can do engineering?

Agency

What can engineering and science do for our world?

Do you see science as relevant to your life?

Do think about science for fun?

Is it important to know chemistry/physics?

PROBE for more info

Follow-up on “I identify relationships between topics from different courses”

Examples?

Why do you think you are good (bad) at it?

What could make you better at it?
Appendix D  Protocol for follow-up interviews

Follow-up, semi-structured interviews with Schuyler and Adlai

1. What are your current college and career plans? (as applicable to the individual)

2. Why did you decide? Who has influenced your decisions?

3. What classes are you taking this year? Why did you choose these?

4. What extracurricular activities are you doing? What other academic interests do you have besides your career? What personal interests do you have? Are your personal interests connected to your academic interests?

5. Do you see yourself as a physics person? What does it mean to be a physics person? Can anyone be a physics person? What are the reasons for your interest in physics? Who else sees you as a physics person? In what ways do they recognize you as a physics person?

6. Do you see yourself as a math person? What does it mean to be a math person? Can anyone be a math person? What are the reasons for your interest in math? Who else sees you as a math person? In what ways do they recognize you as a math person?

7. What do you think about your physics class? Would you recommend that others take physics? Do you think it is important for people to know/understand physics?

8. What do you think about your math class? Would you recommend that others take math? Do you think it is important for people to know/understand math?
9. When we met with you last year, we talked about connecting science and physics to other classes. What do you think about importance of making connections?

10. Can you give me some examples of when you made some connections between physics and other subjects? (probe STEM vs. non-STEM. All students will probably give examples so probe for more and quality of connections to see valuable comparisons between cases.)

11. Specific questions from interdisciplinary affinity model. (factors predicting IA)

   (a) Spent time doing individual work in class? What are some examples? How would you describe your feelings about individual work?

   (b) Topics relevant to their life? Examples? All the time or occasionally?

   (c) Level of conceptual understanding required? Examples? What does conceptual understanding mean to you?

   (d) Questions required several steps of calculations? Examples? Did they help you?

   (e) Teacher’s enthusiasm for physics? Examples? All the time or just certain topics? How did his enthusiasm rub off on you and the rest of the class? (Was it effective for some and not others?)
Appendix E  R Code for Chapter 5 Analyses

#load libraries
library(car)
library(QuantPsyc)
library(psych)
library(Amelia)
library(Zelig)

#load data
#to read data as sent from Harvard
opsci <- read.csv("~/Desktop/Research/OPSCI/Final Data/opscinoformat.csv", header=T)
#to read data with academic performance indices
load("~/Desktop/Research/OPSCI/Final Data/OPSCIwAI.RData")
opsci<--OPSCIwAI

attach(opsci)

#recode education level
opsci$q34edfath<-recode(q34edfath,'9=NA')
opsci$q34edmoth<-recode(q34edmoth,'9=NA')

####factor analysis of q23 (the IA related items)
IAfactors <- as.data.frame(cbind(q23cert,q23rounded,q23expert,
q23relate, q23talk, q23othfield, q23useless, q23team, q23mult,
q23bias, q23diff))

IAefa <- factanal(na.omit(IAfactors), 4, rotation="promax")

#2nd iteration
IAfactors <- as.data.frame(cbind(q23cert, q23rounded, q23expert,
    q23relate, q23talk, q23othfield, q23useless, q23team, q23mult))
IAefa <- factanal(na.omit(IAfactors), 3, rotation="promax")

IAefa

#3rd iteration
IAfactors <- as.data.frame(cbind(q23cert, q23rounded, q23expert,
    q23relate, q23talk, q23othfield, q23mult))
IAefa <- factanal(na.omit(IAfactors), 2, rotation="promax")

IAefa

####Build various models of IA
#The expert component (expert, cert, and rounded)
Expert <- (q23expert+q23cert+q23rounded)/3
opsci$Expert <- Expert

#Integration component (relate, talk, othfield, and mult)
Integ1 <- (q23relate+q23talk+q23othfield+q23mult)/4
opsci$Integ1 <- Integ1

####factor analysis of q24 (the interests in various fields)
InterestFactors <- as.data.frame(cbind(q24lang, q24phys, q24ath
InterestEFA <- factanal(na.omit(InterestFactors), 4, rotation="promax")

# Interest measurement using factors from EFA

SciInterest <- (q24phys+q24bio)/2
EnginInterest <- (q24math+q24engin)/2
ArtInterest <- (q24art+q24lang)/2
SocInterest <- q24soc
AthInterest <- q24ath

# total interest as avg of factors

Interests <- (SciInterest+EnginInterest+ArtInterest+
SocInterest+AthInterest)/5
opsci$Interests <- Interests

## Correlations between academic interests and IA items

r12 <- cor(Interests, Integ1, use="complete.obs")
cor.test(Interests, Integ1, use="complete.obs")

r13 <- cor(Interests, Expert, use="complete.obs")
cor.test(Interests, Expert, use="complete.obs")

r23 <- cor(Integ1, Expert, use="complete.obs")
cor.test(Integ1, Expert, use="complete.obs")

r.test(12600, r12, r13, r23)
## Build physics identity

```
PIinterest <- (q21pinterest+q21pcurious+q21penjoy)/3
opsci$PIinterest <- PIinterest
PIrecog <- (q21ppersononteach+q21ppersonfam+q21ppersonfriend+
           q21phelp)/4
opsci$PIrecog <- PIrecog
PI <- (PIinterest+PIrecog)/2
opsci$PI <- PI
```

## Build STEM identity

```
STEMinterest <- (q21sinterest+q21scurious+q21senjoy)/3
STEMrecog <- (q21spersononteach+q21spersonfam+q21spersonfriend+
              q21shelp)/4
STEMid <- (STEMinterest+STEMrecog)/2
opsci$STEMid <- STEMid
```

# Here are correlations between physics identity and IA
```
cor.test(PI, Integ1, use="complete.obs")
cor.test(PIinterest, Integ1, use="complete.obs")
cor.test(PIrecog, Integ1, use="complete.obs")
cor.test(PIrecog, PIinterest, use="complete.obs")
cor.test(PIrecog, PIinterest, use="complete.obs")
```
r.test(12200,r12,r13,r23)

# and STEM identity correlations

cor.test(STEMid, Interests, use="complete.obs")
cor.test(STEMid, Integ1, use="complete.obs")

## Impute data for use in linear models

OPSCIsub <- subset(opsci, is.na(q13phys1lev)==FALSE)
OPSCIsub <- subset(OPSCIsub, q30collyear==1)

OPSCIsub <- subset(OPSCIsub, select=c("q2money", "q2fame", "q2help",
"q2lead", "q2secure", "q2peopl", "q2invent", "q2devel",
"q2famly", "q2myself", "q2ownd", "q2easyj", "q2excitj",
"q2talent", "q2jobop", "q3mssg", "q4msmg", "q5msins", "q5msinm",
"q6hsprv", "q6hscha", "q6hsmag", "q6hsbac", "q6hsfor", "q6hspub",
"q6hsrel", "q6hsvoc", "q6hsssex", "q6hshom", "q7schoolsize",
"q9hseng", "q11himg", "q13phys1grade", "q13phys1like",
"q15extra", "q15diffcomm", "q15clique", "q15teachthere",
"q15studthere", "q15comm", "q15welc", "q15lost", "q15tight",
"q15out", "q15knew", "PIinterest", "PIrecog", "Integ1", "Expert",
"STEMid", "Interests", "q25med", "q25bio", "q25phys",
"q25engin", "q25math", "q26gender", "q27black", "q27white",
"q27asian", "q27amin", "q27oth", "q27mult", "q28hisp", "q29lang",
"q31homesup", "q34edfath", "q34edmoth", "q35USyou", "q35USfath",
"q35USmoth", "q36fathcar", "q36mothcar", "q36sibcar",
"q36othcar", "q36bettercar", "q36hobby", "q36noint"
## Multiple Imputation code

```r
a.out <- amelia(OPSCIsub, m=5, noms=c("q2money", "q2fame", "q2help", "q2lead", "q2secure", "q2peopl", "q2invent", "q2devel", "q2famly", "q2myself", "q2ownd", "q2easyj", "q2excitj", "q2talent", "q2jobop", "q6hsprv", "q6hscha", "q6hsmag", "q6hsbac", "q6hsfor", "q6hspub", "q6hsrel", "q6hsvoce", "q6hsssex", "q6hshom", "q26gender", "q27black", "q27white", "q27asian", "q27amin", "q27oth", "q27mult", "q28hisp", "q29lang", "q35USyou", "q35USfath", "q35USmoth", "q36fathcar", "q36mothcar", "q36sibcar", "q36othcar", "q36bettercar", "q36hobby", "q36noint", "q36courses", "q36help", "q36tutor"), ords=c("q7schoolsize", "q9hseng", "q11himg", "q13phys1grade", "q34edfath", "q34edmoth"))

#build PI from recognition and interest and recode mother and father ed to dummy variable set

for (i in 1:5)
{
  a.out$imputations[[i]]$PI <- (a.out$imputations[[i]]$PIinterest + a.out$imputations[[i]]$PIrecog) / 2
  a.out$imputations[[i]]$FathEd1 <- recode(a.out$imputations[[i]]$q34edfath, "1=1; else=0")
}
```

154
a.out$imputations[[i]]$FathEd2<-recode(a.out$imputations[[i]]$q34edfath,"2=1;else=0")
a.out$imputations[[i]]$FathEd3<-recode(a.out$imputations[[i]]$q34edfath,"3=1;else=0")
a.out$imputations[[i]]$FathEd4<-recode(a.out$imputations[[i]]$q34edfath,"4=1;else=0")
a.out$imputations[[i]]$FathEd5<-recode(a.out$imputations[[i]]$q34edfath,"5=1;else=0")
a.out$imputations[[i]]$MothEd1<-recode(a.out$imputations[[i]]$q34edmoth,"1=1;else=0")
a.out$imputations[[i]]$MothEd2<-recode(a.out$imputations[[i]]$q34edmoth,"2=1;else=0")
a.out$imputations[[i]]$MothEd3<-recode(a.out$imputations[[i]]$q34edmoth,"3=1;else=0")
a.out$imputations[[i]]$MothEd4<-recode(a.out$imputations[[i]]$q34edmoth,"4=1;else=0")
a.out$imputations[[i]]$MothEd5<-recode(a.out$imputations[[i]]$q34edmoth,"5=1;else=0")
}

# Outcome of PI with IA and controls as predictors
PImodel<-zelig(PI ~ as.factor(q27black)+as.factor(q27white)+as.factor(q27asian)+as.factor(q26gender)+as.factor(q34edfath)+as.factor(q34edmoth)+as.factor(q36fathcar)+as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+AISci
+q13phys1grade+q13phys1like+Integ1, data=a.out$imputations, model="ls")
summary(PImodel)
print(summary(PImodel), subset=1:5)

# Betas for PI model
PIbetafirst <- lm.beta(lm(PI~ as.factor(q27black)+as.factor(q27white)+as.factor(q27asian)+as.factor(q26gender)+as.factor(FathEd2)+as.factor(FathEd3)+as.factor(FathEd4)+as.factor(FathEd5)+as.factor(MothEd2)+as.factor(MothEd3)+as.factor(MothEd4)+as.factor(MothEd5)+as.factor(q36fathcar)+as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$imputations[[1]]))

PIbetasecond <- lm.beta(lm(PI~ as.factor(q27black)+as.factor(q27white)+as.factor(q27asian)+as.factor(q26gender)+as.factor(FathEd2)+as.factor(FathEd3)+as.factor(FathEd4)+as.factor(FathEd5)+as.factor(MothEd2)+as.factor(MothEd3)+as.factor(MothEd4)+as.factor(MothEd5)+as.factor(q36fathcar)+as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$imputations[[2]]))

PIbetathird <- lm.beta(lm(PI~ as.factor(q27black)+as.factor(q27white)+as.factor(q27asian)+as.factor(q26gender)+as.factor(FathEd2)+as.factor(FathEd3)+as.factor(FathEd4)+as.factor(FathEd5)+as.factor(MothEd2)+as.factor(MothEd3)+as.factor(MothEd4)+as.factor(MothEd5)+as.factor(q36fathcar)+as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$imputations[[3]])

156
factor (MothEd4)+as.factor (MothEd5)+as.factor (q36fathcar)+as.factor (q36mothcar)+as.factor (q36hobby)+AIEngl+AIMath+AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$imputations[[3]])

PIbetafourth <- lm.beta(lm(PI~as.factor (q27black)+as.factor (q27white)+as.factor (q27asian)+as.factor (q26gender)+as.factor (FathEd2)+as.factor (FathEd3)+as.factor (FathEd4)+as.factor (FathEd5)+as.factor (MothEd2)+as.factor (MothEd3)+as.factor (MothEd4)+as.factor (MothEd5)+as.factor (q36fathcar)+as.factor (q36mothcar)+as.factor (q36hobby)+AIEngl+AIMath+AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$imputations[[4]])

PIbetafifth <- lm.beta(lm(PI~as.factor (q27black)+as.factor (q27white)+as.factor (q27asian)+as.factor (q26gender)+as.factor (FathEd2)+as.factor (FathEd3)+as.factor (FathEd4)+as.factor (FathEd5)+as.factor (MothEd2)+as.factor (MothEd3)+as.factor (MothEd4)+as.factor (MothEd5)+as.factor (q36fathcar)+as.factor (q36mothcar)+as.factor (q36hobby)+AIEngl+AIMath+AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$imputations[[5]])

PIBetas=NULL

for (i in 1:21)
{
  PIBetas[i]<-mean(c(PIbetafirst[i],PIbetasecond[i],PIbetathird[i],PIbetafourth[i],PIbetafifth[i]))
} 
PIBetas

##Outcome of physics interest with IA and controls (Include recognition as control?)

INTmodel <- zelig(PIinterest ~ as.factor(q27black)+as.factor(q27white)+as.factor(q27asian)+as.factor(q26gender)+as.factor(q34edfath)+as.factor(q34edmoth)+as.factor(q36fathcar)+as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$imputations, model="ls")

summary(INTmodel)

print(summary(INTmodel), subset=1:5)

#Betas for physics interest model

INTbetafirst <- lm.beta(lm(PIinterest ~ as.factor(q27black)+as.factor(q27white)+as.factor(q27asian)+as.factor(q26gender)+as.factor(FathEd2)+as.factor(FathEd3)+as.factor(FathEd4)+as.factor(FathEd5)+as.factor(MothEd2)+as.factor(MothEd3)+as.factor(MothEd4)+as.factor(MothEd5)+as.factor(q36fathcar)+as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$imputations[[1]]))

INTbetasecond <- lm.beta(lm(PIinterest ~ as.factor(q27black)+as.factor(q27white)+as.factor(q27asian)+as.factor(q26gender)+as.factor(FathEd2)+as.factor(FathEd3)+as.factor(FathEd4)+as.factor(FathEd5)+as.factor(MothEd2)+as.factor(MothEd3)+as.factor(MothEd4)+as.factor(MothEd5)+as.factor(q36fathcar)+as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$imputations[[1]]))
as.factor(FathEd5)+as.factor(MothEd2)+as.factor(MothEd3)+
as.factor(MothEd4)+as.factor(MothEd5)+as.factor(q36fathcar)
+as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+
AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$
imputations[[2]])
INTbetathird <- lm.beta(lm(PInterest ~ as.factor(q27black)+as
.factor(q27white)+as.factor(q27asian)+as.factor(q26gender)+
+as.factor(FathEd2)+as.factor(FathEd3)+as.factor(FathEd4)+
as.factor(FathEd5)+as.factor(MothEd2)+as.factor(MothEd3)+
as.factor(MothEd4)+as.factor(MothEd5)+as.factor(q36fathcar)
+as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+
AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$
imputations[[3]])
INTbetafourth <- lm.beta(lm(PInterest ~ as.factor(q27black)+as
.factor(q27white)+as.factor(q27asian)+as.factor(q26gender)+
+as.factor(FathEd2)+as.factor(FathEd3)+as.factor(FathEd4)+
as.factor(FathEd5)+as.factor(MothEd2)+as.factor(MothEd3)+
as.factor(MothEd4)+as.factor(MothEd5)+as.factor(q36fathcar)
+as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+
AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$
imputations[[4]])
INTbetafifth <- lm.beta(lm(PInterest ~ as.factor(q27black)+as
.factor(q27white)+as.factor(q27asian)+as.factor(q26gender)+
+as.factor(FathEd2)+as.factor(FathEd3)+as.factor(FathEd4)+
as.factor(FathEd5)+as.factor(MothEd2)+as.factor(MothEd3)+
as.factor(MothEd4)+as.factor(MothEd5)+as.factor(q36fathcar)
+as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+
AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$
as.factor(MothEd4)+as.factor(MothEd5)+as.factor(q36fathcar)+as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$imputations[[5]])
INTBetas=NULL
for (i in 1:21)
{
  INTBetas[i]<-mean(c(INTbetafirst[i],INTbetasecond[i],
                     INTbetathird[i],INTbetafourth[i],INTbetafifth[i]))
}
INTBetas

##Outcome of physics recognition with IA and controls
RECmodel<-zelig(PIrecog ~ as.factor(q27black)+as.factor(q27white)+as.factor(q27asian)+as.factor(q26gender)+as.factor(q34edfath)+as.factor(q34edmoth)+as.factor(q36fathcar)+as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$imputations, model="ls")
summary(RECmodel)
print(summary(RECmodel), subset=1:5)
#Betas for physics recognition model
RECbetafirst<-lm.beta(lm(PIrecog~as.factor(q27black)+as.factor(q27white)+as.factor(q27asian)+as.factor(q26gender)+as.factor(FathEd2)+as.factor(FathEd3)+as.factor(FathEd4)+}
as.factor(FathEd5)+as.factor(MothEd2)+as.factor(MothEd3)+
as.factor(MothEd4)+as.factor(MothEd5)+as.factor(q36fathcar)+
as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+
AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$
imputations[[1]]))

RECbetasecond <- lm.beta(lm(PIrecog ~ as.factor(q27black)+as.
  factor(q27white)+as.factor(q27asian)+as.factor(q26gender)+
as.factor(FathEd2)+as.factor(FathEd3)+as.factor(FathEd4)+
as.factor(FathEd5)+as.factor(MothEd2)+as.factor(MothEd3)+
as.factor(MothEd4)+as.factor(MothEd5)+as.factor(q36fathcar)+
as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+
AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$
imputations[[2]]))

RECbetathird <- lm.beta(lm(PIrecog ~ as.factor(q27black)+as.
  factor(q27white)+as.factor(q27asian)+as.factor(q26gender)+
as.factor(FathEd2)+as.factor(FathEd3)+as.factor(FathEd4)+
as.factor(FathEd5)+as.factor(MothEd2)+as.factor(MothEd3)+
as.factor(MothEd4)+as.factor(MothEd5)+as.factor(q36fathcar)+
as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+
AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$
imputations[[3]]))

RECbetafourth <- lm.beta(lm(PIrecog ~ as.factor(q27black)+as.
  factor(q27white)+as.factor(q27asian)+as.factor(q26gender)+
as.factor(FathEd2)+as.factor(FathEd3)+as.factor(FathEd4)+
as.factor(FathEd5)+as.factor(MothEd2)+as.factor(MothEd3)+
161
as.factor(MothEd4)+as.factor(MothEd5)+as.factor(q36fathcar)+as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$imputations[[4]])

RECbetafifth <- lm.beta(lm(PIrecog~as.factor(q27black)+as.factor(q27white)+as.factor(q27asian)+as.factor(q26gender)+as.factor(FathEd2)+as.factor(FathEd3)+as.factor(FathEd4)+as.factor(FathEd5)+as.factor(MothEd2)+as.factor(MothEd3)+as.factor(MothEd4)+as.factor(MothEd5)+as.factor(q36fathcar)+as.factor(q36mothcar)+as.factor(q36hobby)+AIEngl+AIMath+AISci+q13phys1grade+q13phys1like+Integ1, data=a.out$imputations[[5]])

RECBetas=NULL
for (i in 1:21)
{
    RECBetas[i] <- mean(c(RECbetafirst[i],RECbetasecond[i],RECbetathird[i],RECbetafourth[i],RECbetafifth[i]))
}

RECBetas
Bibliography


Zahra Hazari, Geoff Potvin, Robert H. Tai, and John Almarode. For the love of learning science: Connecting learning orientation and career productivity in physics and chemistry. Physical Review Special Topics - Physics Education Research, 6(1), May 2010a. ISSN 1554-9178.


R Core Team. R: A Language and Environment for Statistical Computing, 2013. URL http://www.r-project.org/.


