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THE CULTURAL BORDER CROSSING MODEL APPLIED TO THE PHYSICS CLASSROOM

MASTERS PAPER

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ANOTĀCIJA

Studenti cīnās ar mācīšanās fiziku, jo zinātnes ir atšķirīgs, un lielā mērā nepieejamas kultūra. Šīs grūtības var saprast paspārnē kultūras modeļa robežas šķērsošanas. Šis darbs cenšas piemērot robežšķērsošanas metaforu fizikas klasē. Pievēršot uz teorētisko pamatojumu un izstrādājot jaunu novērtēšanas rīku, robežšķērsošanas metafora tiek pierādīts, pastāv iedzīvotāju studentiem. Bez tam, cik lielā mērā šie kultūras faktoru ietekmi studentu atbildes ir noteikta par būtisku. Ja skolotāji uzzināt par šo robežu šķērsošanas metaforu, viņi var darīt labāku darbu pielāgojot vajadzības saviem studentiem, un fizika var būt temats, kas ir pieejama visiem studentiem.

Atslēgvārdi: fizika izglītība, robežšķērsošanas

ABSTRACT

Students struggle with learning physics because the sciences are a different and largely inaccessible culture. This difficulty can be understood under the auspices of a cultural model of border crossing. This work seeks to apply the border crossing metaphor to the physics classroom. By drawing on a theoretical background and developing a novel assessment tool, the border crossing metaphor is shown to exist in a population of students. Additionally, the degree to which these cultural factors impact student responses is determined to be significant. If teachers learn about this border crossing metaphor, they can do a better job accommodating the needs of their students, and physics can be a subject that is accessible for all students.

Keywords: physics education, border crossing

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INTRODUCTION

Despite its pedagogical value, many students struggle to learn physics. The language, processes, and ways of thinking are foreign, and it is a rare student who takes to the sciences and attains mastery. The subject is, to many, a 'different world'. Thus, it is incumbent on the physics teacher to find ways for students to access the realm of physics. In order for the teacher to do this, he must first understand why students struggle to get into physics. By starting with an abstract concept borrowed from cultural anthropology -- the metaphor of border crossing -- this work will seek to provide and justify a way of thinking about student access to physics that will provide a practical solution to this problem.

Students who cross borders effectively are able to adapt their way of thinking to the cultural setting in which they find themselves. Others find the transition from their home culture into the physics classroom to be a difficult one, and they will correspondingly struggle in their studies. When students walk into their physics classroom, does this change in setting prompt a change in how they think? If teachers can predict how students will deal with this transition, then they can do a better job of scaffolding the transition for those who struggle, meeting the needs of those two transitions for less challenging but more lengthy, and providing meaningful learning opportunities for those students whose border crossing is more straightforward.

The aim of this work is to determine whether cultural border crossing exists in real classrooms. This question will be addressed by having students write paired tests: one at school, and one at home. The school test will look like a standard classroom test, with eight multiple-choice questions. The home test will look like a Buzzfeed-style quiz, where participants click icons to find out about some aspect of their personality. These tests will assess the same ideas, but through different cultural media.

If border crossing is real, then the students' results will fit neatly into the categories predicted by the border crossing metaphor. A chi-squared test will be used to determine whether different students experience different categories of border crossing. Then, in a follow-up analysis, a probabilistic model will be used to determine the approximate degree to which border crossing affects students responses on science assessments. Thus, the research question, “Do students experience border crossing in the physics classroom?” will be answered.

There is strong theoretical evidence to believe in the existence of border crossing, including a small number of supporting publications that will be explored in detail. In addition, a categorization similar to that proposed by the border crossing metaphor has emerged from exploratory research. However, to date, there has been no attempt to determine the validity of the border crossing model empirically. This work will cover the theoretical background, outline the development of a novel assessment, and share results from a study of n=27 students.

Section 1 will delve into the theoretical background of culture. Section 2 will motivate and analyze the border crossing model. Section 3 will outline the extensive design, testing, and implementation of the assessment tool.

1 CULTURE

1.1 Cultures

The work of scientists has long been usefully studied as a cultural practice. Kuhn (2012) refers, for example, to cultures as large groups of people with similar sensational experiences (193). Pickering (2010) on the other hand, uses the concept of culture to describe the resources available to a group of scientists, as distinct from the practices the group performs (3). Hestenes (1992) restricts even further, using culture as a synonym for "shared human knowledge" (745). None of these definitions will be adequate to discuss the cultural experiences of students. Kuhn's definition focuses on the people, and neglects their ideas, values, and ways of thinking. The definitions of Pickering and Hestenes, meanwhile, focus on the ideas and tools, rather than the people. A definition is needed that will reconcile the human and the tool.

In this work, as in much contemporary work on the subject, a widely-used meaning of culture that stems from ethnography will be adopted. According to Geertz (1973) culture is "an ordered system of meaning and symbols, in terms of which social interaction takes place" (68). This broad definition allows for the discussion of one's ethnic culture, certainly, and also the culture of a particular school.

Students will necessarily adopt different influences in creating a cultural niche for themselves. They will draw from the cultures of their families, their peers, and their communities. Thus, a given generation's culture may be quite distinct from that of their parents. Likewise, cultures can be different in different parts of the world, or in different families or social groups.

In East Asia, for example, education is highly valued and therefore academic success is expected or praised by parents, and respected by one's peers. American children, meanwhile, often suffer from bullying if they are considered to be too brainy, and many parents value athletic success over academics. Many children today value proficiency with online communication and video game prowess, skills that were mocked a generation ago. Likewise, popular artists and forms of art, forms of social interaction, and attitudes seem to change with the generations. For example, consider how different generations think about the importance of having children, owning a home, or finding a job that will last a career.

Smith, Dugan, and Trompenaars (1996) attempted to categorize national cultures according to indices (6). The scale of universalism-particularism describes the extent to which an individual is motivated by universal values or by particular individuals. The scale of achievement-ascription describes the extent to which individuals are valued: by their achievement in various tasks, or by being ascribed a title or role. The scale of individualism-collectivism describes the extent to which people regard themselves as being individuals or part of groups. Mongolian culture, for example, aligns with particularism, achievement, and collectivism: Mongolians place a high value on their families, and view their work as collective in that context, but there is great renown afforded to individual achievement. Other indices have since been added to the scheme.

1.2 School culture

One further source of students' cultural influences is their schooling. Well-run schools are deliberate about their cultures, choosing to value attributes like thinking, empathy, or respect. Gruenert and Whitaker (2015) argue that "the purpose of a school culture is to get members to adopt predictable behaviours and a common mental model" (4). In this sense our meaning of "culture" is the deep one, including the values, goals, heroes, practices, and ways of knowing for the school, and not merely the superficial sense to which "culture" is sometimes referred in the education leadership literature.

The nature of a school's culture has been well-examined by authors focusing on institutional change and effective leadership. Commonly, this approach to "culture" focuses on the degree to which the school's cultural elements are successful in passing along the core values identified by the leadership to the students. This culture may be classified accordingly, such as in a scheme devised by Gruenert and Whitaker (2015) which runs from collaborative and collegial to Balkanized and toxic. In a toxic school, educators "hold values that don't meet students' needs" (67).

Peterson and Deal (1998) outline the elements of school culture that are accessible to school leaders. They can model and support "underlying norms are of collegiality, improvement, and hard work," identify and elevate "storytellers, heroes, and heroines" and make the school a place where "success, joy, and humor abound" (29).

Gruenert and Whitaker (2015) provide a list of the elements of school culture, including attitudes, the school's mission, the common vocabulary, the place of humour, rituals, norms, roles, symbols, stories, heroes, and the school's deeply-held values (28-40). If there is to be change to the culture of a school, it will have to be via these levers.

1.3 Students' cultures

For the students described later in this work, as in many children in modern times, their cultural influences are multitudinous and diverse. The influences include national cultures of their home countries, such as the way in which they respond to authority or the role they view for schooling. For example, students from Western European countries such as The Netherlands with cultures tilted toward Erasmus, Voltaire, Popper, and philosophies of individual freedoms may see schooling as a process of self-improvement. Students from Eastern countries such China might instead see schooling as a process by which students are molded for contribution to society as adults.

The influences also include ethnic, religious, and clan allegiances. Students with strongly religious backgrounds are typically closer to their families, both in terms of how they spend their time and in terms of how they think about the world. Other influences include those of their era, as outlined above.

Lastly, the students are influenced by the culture of their school, an international school where English is the common language but many others are heard in the hallways, and tolerance and friendliness are valued implicitly, while individual achievement in academics and extracurricular activities is valued via grades and awards.

To see how these cultural ingredients combine, consider this description of a randomly-selected student in this study: she holds a passport to the United States, and her parents work as diplomats for that country. She follows American politics, but has never lived in her home country for more than a few months at a time. Prior to moving to Latvia, she lived in Korea, and India before that. She studies Russian, doesn't hold any particular religious convictions, and is very close to her sisters and parents. She is 11 years old.

Or her classmate: he is from a Latvian family, speaks Latvian, Russian, and English fluently for a boy his age. He reads voraciously, in any of those languages, books by authors from all over the world. His parents are busy, and his nanny is the person with whom he has spent the most of his 12 years. His parents are patriotic, but his two best friends are Russian: one from Moscow, and the other from Jūrmala.

With all these influences, it would be fruitless to attempt to adequately describe the nature of the cultures of a group of students. Instead, the assumption will be made that a student's culture is fairly stable and has not been significantly affected by their studies in the science classroom. Given that the students have six to eight classes, and typically spend no more than an hour per week on homework for any given class, this is a reasonable assumption. Thus, this study will investigate the relationship between a student's experience with the science class, and their culture outside of it. For simplicity, a student's culture minus the impact of their science class will be referred to as their "home" culture.

1.4 Science as a culture

Whether the work of scientists can be described as a culture, or a sub-culture, is a matter of some contention. However, Geertz's definition allows us to adequately describe science as a culture in and of itself. Scientists have ordered systems of meaning and symbols, certainly: theories, experimental procedures, papers, conference proceedings, and so forth. So, too, do scientists interact socially: this is the process whereby results are checked, theories are validated, and knowledge is created. Science is a subset, offshoot, and daughter of the culture of Western empiricism, so it is sometimes called a sub-culture rather than a culture. However, there is no difference effectively between these two labels, so it is just as well to call the work of scientists -- science -- a culture. Beneficially, this allows the home cultures of students, the school culture, and the culture of science to be discussed on equal footing.

Science is a broad field, with a great variety of different approaches, terminology, and procedures. Thus, for the sake of clarity and specificity, this work will focus on physics, a particular field in the domain of science with particularly well-defined vocabulary, procedures for knowledge-creation, and forms of social interaction. For example, through their adoption of mathematical symbols, physicists have a language that transcends languages and convention systems. Every physicist in the world could look at the following equation and understand it describes the propagation of a wave (as, incidentally, Maxwell did with the electric and magnetic fields in 1865):

$$\frac{d^2\psi}{dx^2} = \frac{1}{c^2}\frac{d^2\psi}{dt^2}$$

Likewise, physics has a system for making meaning: the cycle of theory, experimentation, and communication. As in Geertz's definition, this system of symbols and meaning-making facilitates social interaction of physicists, who study in universities, cooperate in labs, meet at conferences, collaborate on papers, and referee each other's work.

The culture of physics, however, is also particularly plagued by pitfalls, inequity, and exclusivity. Addressing the issues with physics is necessarily a cultural question, as it is the culture of physics that causes the problems. These issues begin in school, where physics is seen as a culture accessible only to a few, with notoriously difficult entrance requirements and steep lifestyle demands.

That science emerged as a European endeavour is perhaps understandable historically, but the continued dominance of scientific research by the West is tougher to explain. Sandra Harding (1998:56-61) points to four aspects of science that are unique to the Christian West, which might explain why the discipline is comparatively less accessible for outsiders. First, the notion of nature being governed by a monolithic set of laws is amenable to monotheistic faith, but less accessible for a culture based on polytheism. Second, the legacy of the West prioritizing scientific research of interest to the West -- there is a lot known about grain agriculture, but much less about sorghum, for example. Third, the West exploited the rest of the world during the colonial era, leaving few resources for post-colonial exploration, such as the French mining the natural nuclear reactor at Oklo, Gabon. Finally, Western science attempts to be "value-free" -- Szilard's discovery of the nuclear chain reaction does not make him guilty of the subsequent invention of nuclear weapons -- but the reality is that most cultures are not "value-free", and so "value-free" is, paradoxically, a distinct cultural value.

If the four aspects identified by Harding make it difficult for people of non-Western cultures to benefit from participating in science, there are also many other people who are excluded from science by social and cultural forces. In her seminal anthropological study of particle physicists, Sharon Traweek (2009) noted that women are "marginal" (16) in the culture of Western physics, and virtually absent in the Japanese version. The exclusion of women from physics can be explained by anti-nepotism laws (preventing married scientists from working at the same university), social pressure on women to stay home and raise children, social misconceptions that scientific work is socially unacceptable, traditional sexism, failure to recognize good work done by female scientists, and a plethora of stereotyping that served to perpetuate this situation (Byers and Williams, 2006:6). Under-represented social groups, including ethnic minorities, members of the LGBTQ community, and the poor, are excluded as well.

As a result of this shortage of female physicists, and physicists who are members of underrepresented minorities, there is a corresponding lack of role models for young women and minorities who seek to study physics. This propagates the so-called “gender gap”. Girls who do not see themselves as scientists are less likely to study physics in school. According to a careful study by Kost, Pollock, and Finkelstein (2009) failure to study physics at high school is the biggest predictor of female students’ lack of success at in physics courses at university (12). The majority of the other causes they identified are results of the nature of the courses they pursue. McCullough (2004) and others have suggested that women and men learn equally well in classes that are based on constructivist theory, when students adopt a growth mindset, and when the instructor is able to eliminate factors like stereotype threat and microaggressions (24). These factors are likely to be relevant for underrepresented minorities as well.

While the culture of physics is problematic inherently, the benefits for society and the individual of learning physics are manifest. Engineering, the development of new technologies, and the maintenance of current high-tech projects require a continually-replenished pool of scientific expertise. Likewise, these types of careers are rewarding, both personally and financially, for individuals who pursue them. Thus, while the physics community needs to ‘clean its act up’, this does not mean that teachers should shy away from encouraging their students to pursue physics. If anything, the matter of determining why students do or don’t enjoy and decide to pursue the subject is consequently of utmost significance.

Hestenes and Jackson (1996:4) write that “Physics teachers are the representatives of the physics community in their classrooms” and that these teachers have an obligation “to convey the message that physics is our common cultural heritage — that physics belongs to everyone” and “to wipe out the widespread perception of physics as an elitist foreign culture”. But how can physics teachers, the cultural brokers of their subject firmly embedded in the culture of physics, convey a message of inclusiveness or wipe out the misperception of elitism? The necessary first step for these teachers is to understand how their students are encountering and dealing with their classes as a cultural phenomenon.

However, the theories of culture presented thus far -- those of Trompenaars, Gruenert and Whitaker, and Harding -- provide little insight into how cultural forces are acting on the scale of the individual. How does a student's home culture interact with the culture of his school, or of the science classroom? In order to address this question, a profound metaphor about the functioning of cultures, and about how people mediate between them, will be required.

2 BORDER CROSSING

2.1 The metaphor of border crossing

Given the problematic nature of the culture of physics, there is a clear need for a framework by which educators can understand and negotiate culture in the classroom. Henry Giroux's metaphor of a "border crossing" provides such a framework, and the work of Costa and Aikenhead in adopting that structure to the subculture of science has produced a structure that can be used by educators and theorists.

The concept of border crossing begins with a simple simile: our experiences interacting with other cultures are like our experiences when we cross geographical borders. In addition to providing a vivid analogy, this also offers the use of a vocabulary associated with travel, which will be useful in discussing cross-cultural issues.

Giroux (1992) suggests three main reasons why border crossing is a valuable metaphor. First, by using a metaphor that provides clear distinction and delineation of different cultures, we are forced to recognize the margins between cultures, which is where much cultural navigation takes place. Second, the metaphor suggests a clear duty for educators: to prepare students to confront, cross, and challenge borders in their lives. Third, the border metaphor makes clear the historical and contemporary power structures that have combined to build the world we inhabit over and across the extant cultural borders, and empowers individuals to critically examine and combat different extensions of power (20-21).

Most importantly, the border crossing analogy reminds us that our perspectives are limited, that others may also be right, and that the best voices are those that speak with multiple accents. Equally, the analogy disposes with false notions of cultural equality, emphasizing instead that cultures are different (24).

2.2 Student border transitions

Adapting this border-crossing analogy to students' experiences at school began with the work by Phelan, Davidson and Cao (1991), who conducted a two-year study of 54 high-school students in California. The students were found to cluster into four groups, according to their success and support with crossing borders between the "world" of their families, their peers, and their school. The four groups are distinguished by the nature of the students' border-crossing.

The first group find their home and school worlds to be congruent, and consequently experience a smooth transition when they cross the border. These students and their friends tend to comfortable with the academic environment, and are more likely to be successful. They are viewed the same way by their families, their peers, and their teachers. In Phelan, Davidson, and Cao (1991) these students tended to be white, and of European-American descent (60).

The second group experiences different worlds at home and at school, but have developed strategies and skills for managing the border crossing. These students tend to code-switch, acting and speaking differently at home and at school, and allow little interaction between these two world. Some of these students are partially successful at incorporating different worlds into their personality, but this transcultural approach tends to exact a steep emotional price from those who attempt it. The students in the second group tended to be high-achieving students from ethnic minority families (65).

The third group also experiences different worlds, but lack the skills and strategies to manage a border crossing. Instead, they find the border crossing to be difficult, and may be able to do it successfully only in certain circumstances. These students will tend to prioritize their home lives or their friends, and are often at risk academically. For these students, learning activities that take into account their skills and abilities can often make the difference between academic success and failure (74).

The fourth group experiences different worlds at home, at school, and with their peers, but is unable to overcome the barriers between these worlds. Unsurprisingly, this often leads to lack of success in one or more worlds: poor grades, poor peer relationships, or poor family dynamics. These students come from all walks of life, but tend to be minorities. These students often require specialized assistance such as counseling (78).

2.3 Science students

The model of Phelan, Davidson and Cao was applied to science learning, in particular, by Costa (1995). Costa interviewed 43 high-school students, also in the USA. The students were enrolled in either a chemistry class or an earth science class. The former has a reputation for being a demanding, pre-university science class, while the latter is often chosen by weaker students seeking to meet a science course requirement.

Costa's first group is similar to the first group from Phelan, Davidson, and Cao. The students experience congruent worlds of science at home and at school. One student reported using a small chemistry set at home; other students typically have parents with scientific, engineering, or medical backgrounds. The border crossing encountered by these students is a smooth one, and many viewed themselves as scientists and planned to pursue sciences at university. Costa (1995) dubbed this first group "potential scientists." (317)

The second group in Costa's scheme view science as valuable, but not as part of their personal trajectory. Costa points out that many in this group, which she dubs the "other smart kids", are capable of doing well in science, but choose not to. Thus, although there are overlaps with Phelan, Davidson and Cao's second group, these groups are not identical. These students tend to do well in school, but do not find their science classes to be especially meaningful (319).

Costa's third group, the "I don't know" kids, often experience a difficult border crossing between their home culture and the subculture of science. Their common, titular, refrain of "I don't know" comes because they haven't developed a clear understanding of the nature or processes of science, and typically think of the course as being indistinct from the rest of their classes. Depending on the strategies they have developed for school and the nature of the instruction, they may be successful, or they may struggle in a science classroom. (321).

The "outsiders" in Costa's scheme fall into Phelan, Davidson and Cao's fourth category. These students find it impossible to cross the border between their home culture and the subculture of science. They tend to be doing poorly academically, but are not unintelligent. Typically, they have a negative emotional opinion of their science classroom, teacher, and/or instruction (324).

Lastly, Costa identifies a group of students that defy categorization in Phelan, Davidson and Cao's scheme. These students would be considered outsiders by most metrics, but they have a particular interest, investment, or attachment to the subculture of science that makes it clear they are being let down by the education system, rather than by a clash of cultures. Costa describes two such "inside outsiders": a young woman who grapples with challenges in her life outside of school, and a teen mother whose transcript was incorrectly produced during a switch between schools, barring her from taking the university-track courses of which she is capable (327).

In a follow-up article, Aikenhead proposed a sixth category, the "I want to know" student. These students find science to be personally meaningful, but face strong cultural barriers that prevent them from being considered potential scientists. Aikenhead, 2001, suggests that this group of students might be applicable for those who pursued a particular challenging scientific course in the UK that led to vocational and technical, rather than academic, training (9). However, these students are acknowledged by Aikenhead to be rare, and will not be accounted for in this work.

The idea of identifying categories of students is not a new one. Using questionnaires designed to determine motivation, the affective dimension, and self-regulation, psychologists Shell and Husman (2008) found five types of students in psychology classes. Pond and Chini (2015) extended this work to university-level physics courses, where they found the same clustering. The groups are: strategic learners who are motivated and equipped to learn, knowledge-builders who are motivated but less engaged, surface learners who are seeking to pass the course but show little engagement, apathetic learners who have no motivation, and learners experiencing learned helplessness with motivation but no strategies for success. Stripped of the psychological predilections, these five categories are nicely aligned with the border-crossing groups.

Table 2.1.

Table comparing student groups from Pond and Chini (2015) with the border-crossing categories developed by Costa (1995)

Pond and Chini (2015)	Costa (1995)
Strategic: motivated to learn, able to use self-regulatory strategies as required	Potential scientists: congruent home and science cultures, making for fluid border-crossing
Knowledge-Building: motivated to learn, but not engaged with the course as actively as strategic learners	Other Smart Kids: different home and science cultures; comfortable with the culture of school and capable of navigating the border-crossing, but do not value science personally

Surface: not engaged with the course, and primarily concerned with obtaining a passing grade	I Don't Know Students: incompatibility between home and school cultures results in struggle and frustration in school, often resulting in seeking strategies to obtain minimally-acceptable grades
Apathetic: unmotivated and unengaged; might want to pass the course, but no personal interest in the subject	Outsiders: science culture is alien, with a border-crossing that is perilous, often because of a mistrust of the culture of the school
Learned-Helpless: motivated to pass, but unable to access self-regulation strategies	Inside-Outsiders: have a personal interest in science, but unable to cross the border because of the influence of the school culture

In addition to providing a theoretical motivation for the existence of a discrete categorization scheme, the border-crossing paradigm also explains much about the different groups. Shell and Husman's strategic learners are the potential scientists who, in a physics classroom, have the cultural fluency to understand and master their learning environment. Their knowledge-builders are the other smart kids: these students' lower engagement is because the physics classroom is a foreign cultural experience for them. Thus, it is clear that the border-crossing analogy is a powerful and useful tool for educators.

2.4 Application to energy

As a concept that has many different understandings, both scientific and otherwise, energy provides an ideal test-case for how understandings may be different across cultural borders. As the term is used in everyday parlance across the world (and it survives into many languages as a loan word), we may identify three loci of meaning. These focuses overlap, and one person's understanding of the term "energy" is likely to comprise an admixture of the three everyday loci alongside the scientific understanding. Other meanings of "energy" might refer metaphorically to one of these understanding.

In the *vis-viva* sense, energy is the ability of living things to move, respire, procreate, and remain alive. In this sense, one may say that a tree has living energy, while a stone has no energy. There is, here, perhaps some overlap with the idea of a soul. Joan Solomon (2003) identifies the scientific work of Leibniz as helping to support the theory of Vitalism and the related concept of "vital force", an "indwelling and enduring" quantity that is passed from living organisms to their progeny (11).

In the *flux* sense, energy is a quality of objects that are in motion. A faster-moving object will have more energy. Here, one may say that a stationary car has little energy, but a car that is moving has plenty of energy. This is similar to the scientific quantities of momentum and kinetic energy, although both of those also depend on the object's mass. This understanding arose historically with the industrial age, when the power of steam machines led to a revolution in how people in industrial nations came to see the world.

In the *qi* sense, energy is the potential of a person or a system to attain desirable outcomes, or one's alignment with the natural order of things. Here, energy is primarily used in reference to humans. A highly-energy young person might be a dynamic innovator, destined to achieve great things in his or her field of choice. Alternatively, we may think of a person's energy as an indicator of their spiritual state of being. This concept originates in Eastern religion and also, as Solomon (2003) indicates, is closely related to the Aristotelian conception as "potentiality for change" (8).

Scientists use the concept of energy to refer to one unique thing, a quantity that is generally conserved, and whose transfer and transformations underlies much of the change in the universe. However, since energy is used in a variety of different ways in different fields, no single definition has university applicability. Helen Quinn (2014) suggests that students learn about energy by "exploring it", and that students should learn about energy "by experiencing and applying" the concept "in multiple contexts" (15).

The physicist's definition is the most canonical: energy is the quantity that is changed via work, which is defined as the line-integral of a a force along the path over which the force is applied. Scientists typically understand different forms of energy, including kinetic (the energy of motion), gravitational potential, thermal, chemical, and others. Each of these forms is well-understood theoretically, and can be calculated based on fundamental or characteristic quantities.

Students making the border-crossing between their home culture and the culture of their physics class will experience a tension between their everyday conceptions of energy and the technical meaning that is employed in the classroom. For "potential scientists", the tension will be small because their home understanding of energy will be similar to the understanding in the physics classroom. For "other smart kids", "I don't know kids", and "outsiders", the tension will be stronger. Students in this case may respond in a variety of culturally-rich ways: rejecting the physics culture, adopting both but segregating them, or attempting to fuse the cultures into an awkward superposition of conflicting definitions.

3 EXPERIMENT DESIGN AND DATA COLLECTION

In order to test the theory that border crossing leads to distinct and predictable student experiences, a paired-test experiment was conducted. After identifying an appropriate community of participants, the apparatus was developed and employed.

The idea of a paired test is that participants will answer similar questions at school, in a standard classroom setting, and at home, in a way that is better aligned with their home culture. By analyzing the differences between these two tests, conclusions can be reached about the nature and existence, or otherwise, of cultural border-crossing.

3.1 Population description

The participants in the study were students at the International School of Latvia. The school attracts a diverse group of students, with a broad range of cultural backgrounds. The data used represents students from more than 15 countries, including Latvia, Russia, Lithuania, Belarus, Finland, Sweden, Switzerland, France, Turkey, Ukraine, Armenia, Uzbekistan, India, Korea, and the USA. Many of the students have multiple nationalities, because their parents are from different countries, or because their families migrated during their childhood. Many other students have lived substantial amounts of time out of their home country. Others are so-called 'third-culture kids', described by Fail, Thompson and Walker (2004) as "cosmopolitan people who feel comfortable in a variety of environments but lack a sense of belonging in any one" (323).

Likewise, cultural dimensions like family orientation vary, from children raised by professional nannies, to children from very tight nuclear families. Another cultural dimension is religion, and this too varies, including students who subscribe to all three of the major Abrahamic religions, along with several raised in atheist homes. Popular culture influences vary as well, including assorted predispositions for Korean music, Russian television, American movies, British humour, and online culture.

One limitation of this study is that while a cross-section of socio-economic classes is represented, there is a bias toward the wealthy. Many of the students attend the school because of their parents' work, but others pay a tuition of about EUR 13 000 annually. Thus, there will be an oversampling of wealthy children. This should not matter: children are children, and the essential point in this study is that the students are experiencing a border crossing of some nature, between their home culture and the culture of the science classroom.

In total, data from 51 students is used to develop, validate, and conduct the experiment. Of those, 27 participants' data is used to draw conclusions in the final analysis. This limitation is due to the small class sizes at the school.

3.2 Preliminary instrument

A preliminary test was devised to evaluate the extent to which students' home cultures could be assessed. In this test, students would write a test at school composed of six questions to assess their understanding of six different types of energy: light, kinetic energy, friction, thermal, electric, and gravitational potential. The questions are multiple-choice, and both questions, answers, and distractors were developed in line with the strategy outlined by Herrmann-Abell and DeBoer (2014:103-133).

First, targets were set for each of the six identified concepts related to energy. For light, the scientific understanding is will be tested is that that light waves bear colour and are absorbed and emitted by physical objects. For kinetic energy, the scientific understanding is that objects will continue to move at a constant velocity unless work is done on them to change that. For friction, the scientific understanding is that friction arises because of a force perpendicular to the area of contact. For thermal energy, the scientific understanding is that thermal energy is transferred from areas of high temperature to areas of low temperature. For electric energy, the scientific understanding is that charge carriers bear energy around a circuit. Finally, for gravitational potential energy, the scientific understanding that will be tested is that objects fall with the same acceleration, regardless of mass.

The classroom instrument consists of six questions. The first three questions are multiple-choice, and target applications of energy concepts that the students have not yet studied in their physics class. The final three questions ask students to answer, and provide elaborations on their answers. These answers were assessed as either being in-line with the scientific understanding of "energy" or as falling into one of three alternative understandings. The questions are presented in Table 3.1.

Table 3.1.

Questions for the preliminary instrument

1. Electric outlets on the wall have two holes. Why? a. The electricity needs somewhere to go after all the electrons are used up. b. The electricity is only about 90% used in most devices. c. The second hole is just there for safety. d. As much electricity flows out of the wall as into the wall.	4. Imagine you are in an elevator standing on a scale. The reading is 600 N. The wire holding the elevator is cut. What force will the scale read while you are freely falling? Why?
2. If you put an ice cube into a cup of tea, which of the following happens? a. Cold from the ice goes into the tea. b. Heat from the tea goes into the ice. c. Both (a) and (b) d. Heat rises into the ice cube only because it is floating at the top.	5. Imagine you kick a book and it slides along the ground. Describe the motion of the book after the kick. Which forces are acting on the book?
3. Look at something blue. Why is it blue? a. It is releasing blue light. b. When white light hits it, the red and green colours are "eaten" and only blue is reflected. c. Light carries the colour information to your eyes. d. It just is blue. It has nothing to do with light.	6. Two toy cars are traveling in opposite directions. They collide and get stuck together. After the collision, they move to the left at a constant speed of 0.20 m s^{-1}. Draw free body diagrams for the two cars. Which car is applying a stronger force to the other?

In addition, students were given a task to complete at home with one of their parents. They were asked to do this with whichever of their parents was most available, since this is also likely to be the person with whom they would most often talk about energy-related concepts. These questions addressed identical issues, but were written in a more everyday vernacular to evoke the understandings of the home culture, and to be more accessible to the parent. This was shared as a Google Form, and is presented in Figures 3.1 to 3.6.

Figure 3.1.

Question 1 from the preliminary instrument

This is a picture of red smoke during the day.

If you looked at night with a flashlight that shines only red light, what would you see?

	Only the green plants.	Only the red smoke.	Neither the red smoke nor the green plants.	Both the red smoke and the green plants.
Student	○	○	○	○
Parent	○	○	○	○

Figure 3.2.

Question 2 from the preliminary instrument

A dog is pulling a human at a constant speed.

Which statement is correct?

	The dog is pulling with a stronger force because they are moving to the left.	The dog is pulling with a stronger force because the human has a larger mass.	The human is pulling with a stronger force because the human has a larger mass.	The dog and the human are pulling with equal forces.
Student	○	○	○	○
Parent	○	○	○	○

Figure 3.3.

Question 3 from the preliminary instrument

A bowling ball is slowing down as it rolls.

Why is the ball slowing down?

	Gravity is pushing the ball down into the floor.	The original push on the ball is becoming smaller.	The movement energy of the ball is becoming smaller.	Friction is acting because the ball slides as is rolls.
Student	○	○	○	○
Parent	○	○	○	○

Figure 3.4.

Question 4 from the preliminary instrument

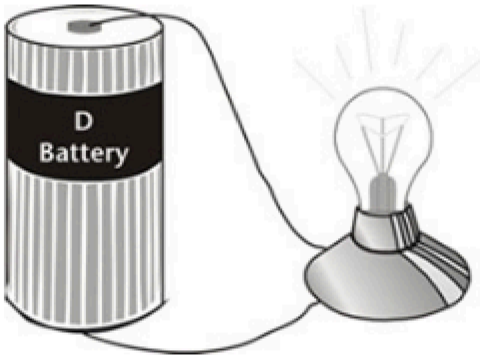
If you sit on an iron bench during the winter, the bench will feel colder than the air.

Why does the iron feel colder?

	Heat rises up from the iron into your body.	Heat flows quicker into iron than into air.	Cold flows quicker from iron than from air.	Iron is colder than air.
Student	○	○	○	○
Parent	○	○	○	○

Figure 3.5.

Question 5 from the preliminary instrument



A lamp needs two wires connected to a battery in order to light.

Why?

	The electricity is not 100% used up by the lamp.	The electricity flows faster in one wire and slower in the other.	Just as much electricity flows into the lamp as out of the lamp.	The second wire is not actually necessary.
Student				
Parent				

Figure 3.6.

Question 6 from the preliminary instrument

There are two stones. One has a larger mass. If you drop both stones at the same time, which will happen?

(the stones are dense, so air resistance will not matter)

	The stone with a larger mass will hit the ground much earlier.	The stone with a larger mass will hit the ground a little bit earlier.	The stone with a smaller mass will hit the ground first.	The stones will hit the ground at exactly the same time.
Student				
Parent				

After this data collection, each of six questions has been answered three times: once by the student in school, once by the student at home, and once by the parent at home. If there is no border crossing, students would select the same answer at home and at school. And if the cultural influences from students' parents are not significant, then students and parents would not tend to select the same answers. The school test and home questions are aligned according to Table 3.2.

Table 3.2.

Aligned questions in the school and home versions of the preliminary instrument

Topic	School question (on Table 3.1)	Home question (Figures 3.1 to 3.6)
Light and colour	3	3.1
Balanced forces at constant velocity	6	3.2
Friction	5	3.3
Direction of thermal energy transfer	2	3.4
Energy in electric circuits	1	3.5
Objects in free-fall	4	3.6

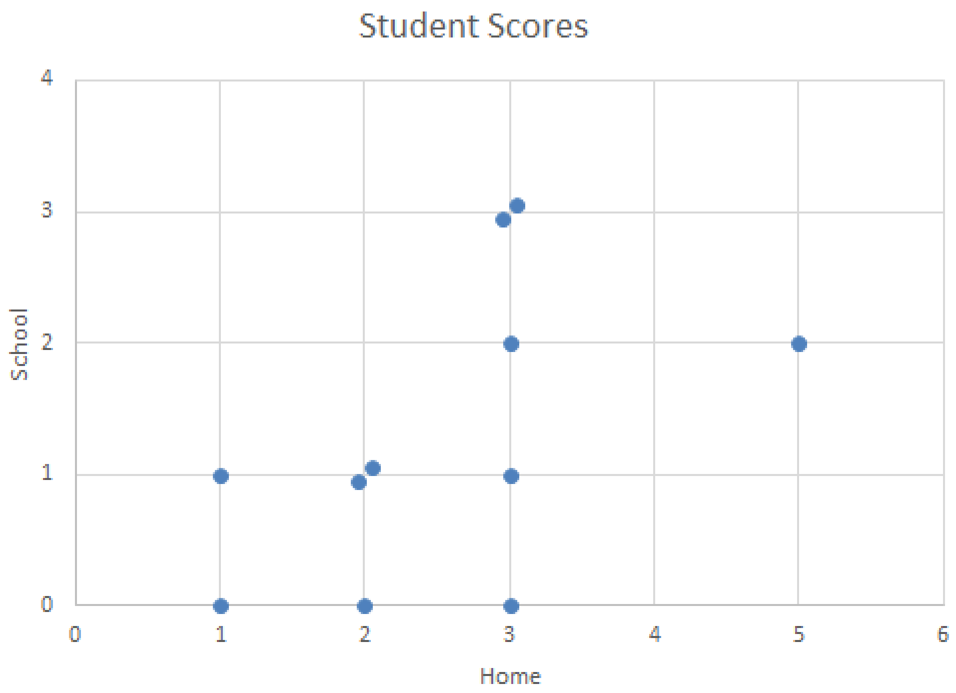
In total, 11 sets of data were usable. Others needed to be excluded because they were incomplete or because students failed to follow the instructions. Of the 11, 7 students indicated that they translated some words during the activity. Each of these were followed-up, and it was ensured that the intended meanings were inferred. The raw data is presented in Appendix 3.

Several questions can be answered by this preliminary study. First, is student understanding of energy consistent between the classroom and home settings? If this were the case, it would be expected that students who answer a large number of of the questions with the scientist's answer at school would also provide the scientist's answer at home. Thus, a two-variable test for independence can be conducted. The Pearson product-moment correlation coefficient r was calculated to be +0.511, in comparison with the critical value of 0.602. Thus, it cannot be claimed that the two test scores are correlated, and the suggestion that students think differently about energy at home and school is supported. Visually, on

Figure 3.7, a correlation should be expected if student knowledge were independent of their cultural medium; however, the correlation is a weak one, suggesting that something else is causing students to think differently in these different settings.

Figure 3.7.

Number of questions students answered scientifically in the home and school conditions for the preliminary instrument



However, it is not clear that the number of correct questions is an ordinal, rather than interval, quantity. For example, a student who answers two questions scientifically is not obviously twice as scientifically-minded as a student who only answers one question in that way. In such a case, the Spearman ρ should be calculated instead. Here, it was found that ρ = 0.569, compared with a critical value of 0.618, and the same conclusion stands.

A second question is whether the student and parent answers are connected. Here, it is not necessarily the case that a larger number of scientifically-aligned answers is better. In other words, the data is categorical, rather than ordinal. Thus, a chi-squared test, applied to each question, was performed. There were 11 students, and 6 questions, resulting in a total of 66 data points. The null hypothesis is that the likelihood of a student giving a scientific answer is independent of the parent giving a scientific answer.

Table 3.3.

Contingency table for home answers in the preliminary instrument

Home Results	*Student Scientific*	*Student Non-scientific*	*Total*
Parent Scientific	*21*	*5*	*26*
Parent Non-scientific	*7*	*33*	*40*
Total	*28*	*38*	*66*

The chi-squared statistic (including the Yates continuity correction) for this contingency table is 25.81. Since the critical value is 3.841, it can be claimed that the student and parent answers are not independent. Thus, the suggestion that student understanding of energy is influenced by the student's home culture is strengthened. It can be concluded with some confidence that student and parent answered are related, as would be expected if culture plays a role in understanding of scientific concepts.

Although these results support the border-crossing model, they are insufficient to draw a conclusion. One problem is that the number of samples is too small. A larger methodological issue is that the home test prompted discussions between the students and their parents, which has the potential to influence the response for either. It was hoped that the parent's answers would provide a proxy for the student's home culture, but this appears not to be the case in practice. Neither should this work in theory, either: students' 'home' cultures are influenced by their families, friends, the media, and other sources, and not just their parents.

In addition, according to student reports, the exercise was treated by both parents and students as a sort of homework. That is, it was seen as a mission from the science class into their homes. Thus, it is possible that the quiz pushed some participants toward thinking, "What did my science teacher say about this, back in school?" Such a reaction would invalidate the experiment. A further issue was that the response rate was quite low. Many of the student participants were unwilling or unable to get a parents to help them with the exercise.

Thus, it was clear that a new methodology would need to be devised that could extend these results. The new procedure would need to rely only on students' input, and would require the creation of new questions, validification by experts, and a better way to access students' home cultures.

3.3 Instrument development and validation

To develop the instrument, literature on assessment of energy concepts was consulted, incuding Herman-Abell and DeBoer (2014) and Solomon (2003). Typically, authors refer to 'misconceptions', and these served as the source for the questions for the instrument. On one hand, these 'misconceptions' are fertile ground for assessing a student's alignment with the scientific understanding of energy, and thus useful. However, is rather unfortunate that these different ways of understanding are labeled 'misconceptions' rather than 'different conceptions'. Therefore, that term will not be used henceforth.

Hermann-Abell and DeBoer (2014) identified the following components of the energy concept as being particularly relevant: motional, thermal, gravitational potential, and elastic energies, and the issues of the transfer, transformation, and conservation of energy (114-128). Elastic energy is a concept that is less familiar to many students, so it was neglected for this study. However, electrical energy is quite relevant for society today, so it was added to the list.

In addition to the resulting six areas, two further issues were deemed important. First, the idea of energy being a measurable quantity that can be added to, or subtracted from, a system. Second, the use of the energy concept in describing our electrical and power generation infrastructure. These two additional concepts were thought to address some fundamental understandings about energy that are usually overlooked by scientists who have a thorough and mature understanding of the concept.

Finally, the topics of energy transformations and conservation of energy were reconciled into a single question, as these two concepts are closely related, and difficult to disentangle.

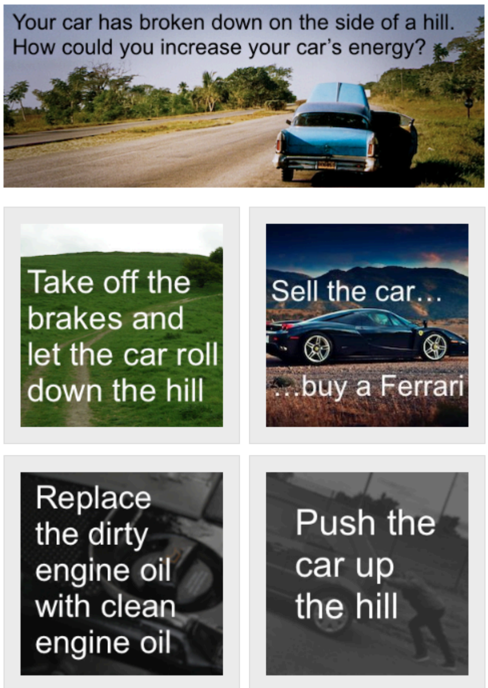
These eight topics led to eight multiple-choice questions. Each question has four answers: the scientist's answer, and three distractors that correspond to the three other understandings of energy discussed above (*vis-viva*, *flux*, and *qi*).

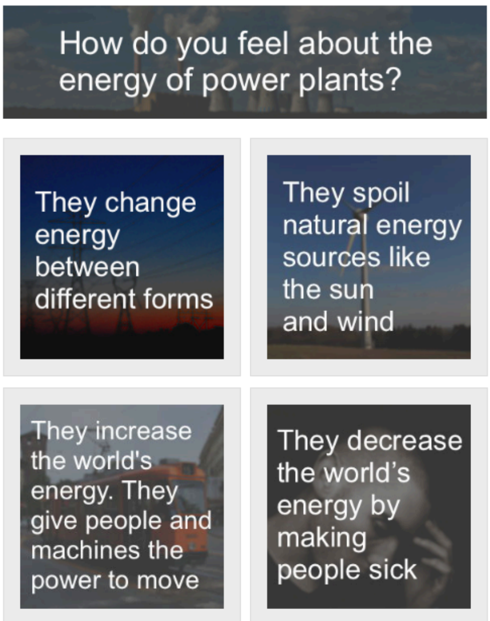
The questions were written in two formats: the standard classroom-style quiz (see Appendix 4) and in a style more amenable to students' home cultures. The standard-style questions were written in the same way as for the preliminary instrument: once the area had been identified, a key concept within that area was chosen, and a question was written to address that. Table 3.4 illustrates the key concepts and the questions.

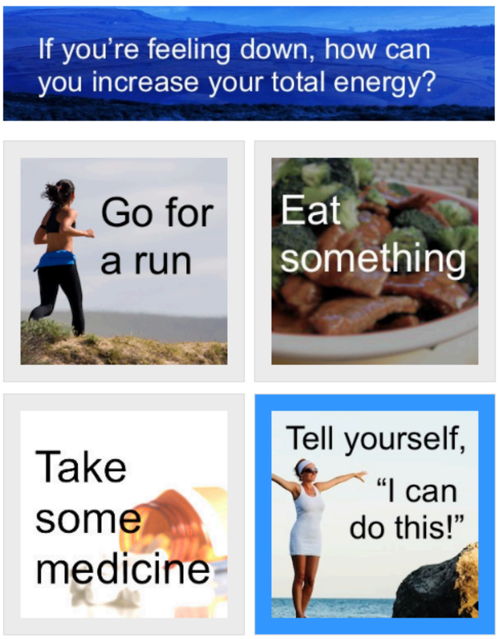
The amenable style was chosen to be in the form of a Buzzfeed-style quiz. For these popular online quizzes, the participant reads a question and then clicks the illustrated answer that most applies to him/herself. Because this style of quiz is highly user-centered, it was hoped that writing the questions in this format would allow the participants to remain in their home cultures while taking the quiz. Care was taken to choose images to help illustrate the answers, which could be useful for participants with weaker English-language skills, and help to prevent misunderstandings altogether. The questions appear as in Table 3.4, below.

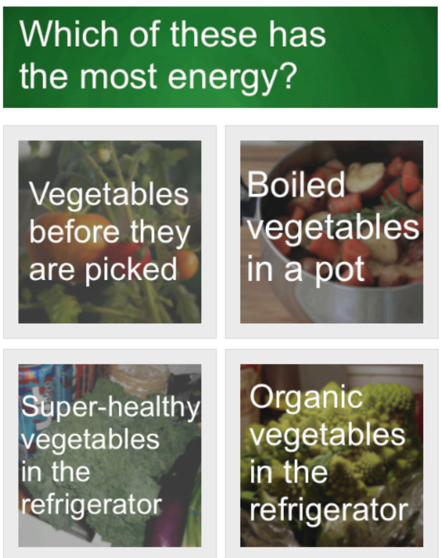
Table 3.4.

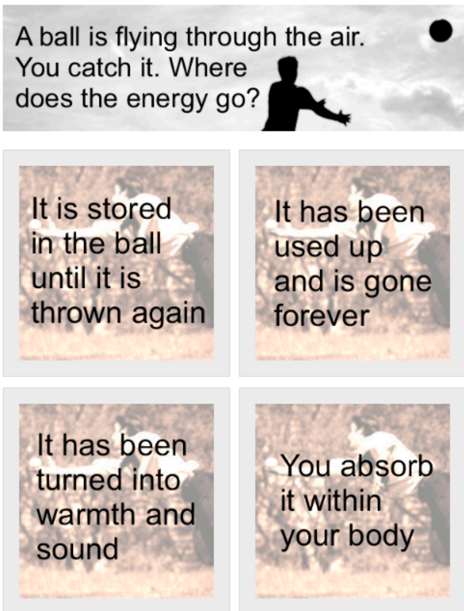
Questions for the standard-style classroom quiz, along with key concepts and related questions from the online quiz

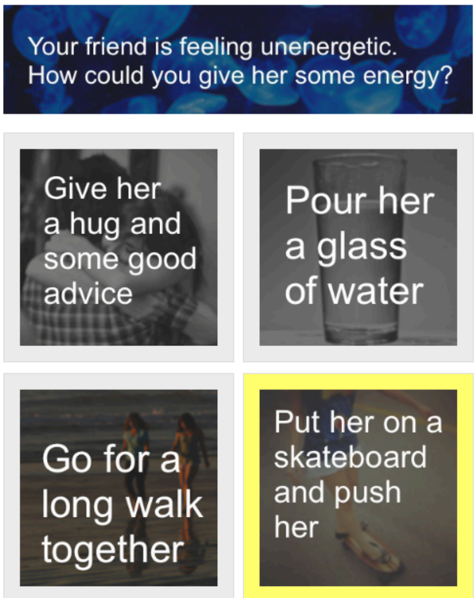
Question 1				
Topic:	Gravitational Energy			
Key Concept:	Objects have more (potential) energy if they are at a greater height			
Question:	A shoe box is sitting in the centre of a table. In which of the following situations is the box's energy increasing?			
Answers:	scientific	*vis-viva*	*flux*	*qi*
	The box is lifted and placed on a high shelf.	A turtle is placed inside the box.	The box is gently pushed off the edge of the table and falls to the floor.	A smiley face is drawn on the side of the box.
Online Equivalent				

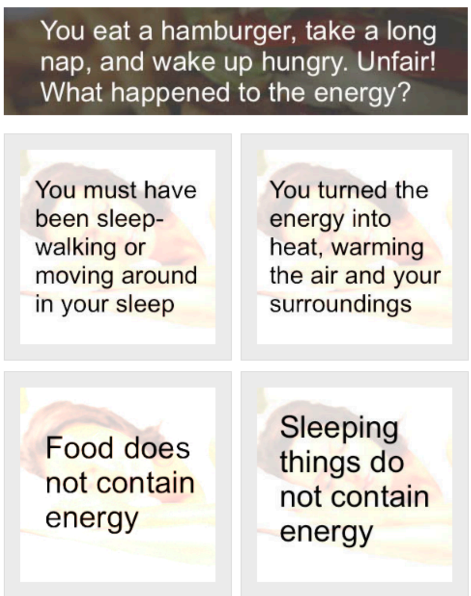
Question 2				
Topic:	Power generation			
Key Concept:	Power plants transform energy into a form that is more useful for humans, but with some inefficiency			
Question:	Which statement about power plants is the most true?			
Answers:	scientific	*vis-viva*	*flux*	*qi*
	Power plants convert energy from one type to another, and some of the energy is lost into the environment.	Power plants decrease the total energy in the world because they emit pollution, which causes people and animals to become ill.	Power plants increase the total energy in the world by providing power to machines which help move the economy forward.	Power plants don't do anything with energy, but they can spoil the landscape if they are built in the wrong location.
Online Equivalent				

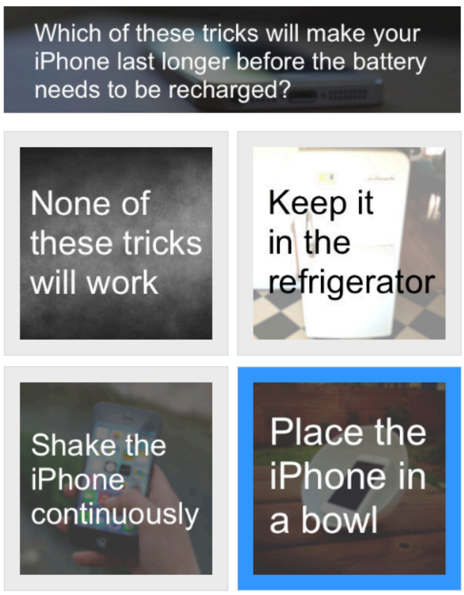
Question 3				
Topic:	Energy as a quantity			
Key Concept:	Energy is a quantity that can be measured and compared.			
Question:	James (a new Buddhist monk) has been meditating at a monastery, halfway up the side of a mountain. His lama tells him that he must seek to maximize his total internal energy. How can he do this?			
Answers:	scientific	*vis-viva*	*flux*	*qi*
	Climb to the top of the mountain.	Stop eating meat and processed food, and eat only fresh vegetables, nuts and rice instead.	Run to the bottom of the mountain as fast as he can.	Stop being a monk, and get an exciting job in the financial sector.
Online Equivalent				

Question 4				
Topic:	Thermal energy			
Key Concept:	The thermal energy of an object is determined by its mass and temperature			
Question:	Salma is conducting an experiment about the thermal energy content of different substances. She finds that the thermal energy of 10 g of wood increases by 26 J when she increases the temperature by 1.0 deg C. According to Salma's experiment, which of these items would contain the most thermal energy?			
Answers:	scientific	*vis-viva*	*flux*	*qi*
	They all are the same.	A very small tree with a mass of 200 g that is growing in the sunlight, on a day when the temperature is 25 deg C.	A wooden toy train with a mass of 200 g that moving with a speed of 3.5 m/s along a track in a room that has a temperature of 25 deg C.	A sacred wooden artifact, with a mass of 200 g, that has been stored in a temple for 400 years at a constant temperature of 25 deg C.
Online Equivalent				

Question 5				
Topic:	Kinetic energy			
Key Concept:	Kinetic energy is the energy that an object possesses by virtue of its motion			
Question:	A stone is rolling along the ground and slows to a stop. Which of the following describes the energy transformations the stone goes through?			
Answers:	scientific	*vis-viva*	*flux*	*qi*
	Kinetic energy in the stone is transformed from into thermal energy through friction.	Kinetic energy from the person who pushed the stone is absorbed by the earth.	Kinetic energy in the stone is lost when the stone stops.	Kinetic energy from the person who pushed the stone is retained by that person.
Online Equivalent				

Question 6				
Topic:	Energy transfers			
Key Concept:	Quantities of energy can be transferred from one object to another.			
Question:	An engineer is building a new type of machine that can do many different tasks. Which of these corresponds to the greatest amount of energy output from the machine?			
Answers:	scientific	*vis-viva*	*flux*	*qi*
	Propelling a 20 kg mass from rest to a speed of 5.0 m/s.	Holding up a tree for 6 months as it grows from a 1.0 kg seedling into a 50 kg sapling.	Shaking a can of paint by moving it back and forth 10 cm at a rate of 5.0 times per second for 2.0 minutes.	Generating 800 random numbers per second for the website random.org for 30 seconds.
Online Equivalent				

Question 7				
Topic:	Energy transformations			
Key Concept:	Energy can change from one form to another, must the total energy must be conserved when this happens			
Question:	Paulina sees her fancy new purse fall from a table to the floor. Which of the following best describes the energy transformation?			
Answers:	scientific	*vis-viva*	*flux*	*qi*
	The purse had potential energy because it was on the table, and all of that energy changes into movement energy as it falls.	The purse had energy because Paulina put it on the table, and some of that energy is lost as it falls.	The purse starts off with no energy, and the energy increases as it falls.	The purse lose a little energy, but it is mostly still there; you just need to clean it off.
Online Equivalent				

Question 8				
Topic:	Electric energy			
Key Concept:	Electric current bears energy, and batteries provide electric current corresponding to the circuit to which they are connected.			
Question:	There is a certain type of flashlight which allows you to control the brightness by turning a knob. The flashlight consists of a battery, wires, and a light bulb. Which statement best describes what happens when you turn the knob to increase the brightness?			
Answers:	scientific	*vis-viva*	*flux*	*qi*
	When the knob is turned, less energy is transformed into heat in the wires.	When the knob is turned, the wire's temperature increases, which allows more electricity to flow.	When the knob is turned, the electricity flows through the wire more quickly.	When the knob is turned, the wire becomes more sensitive and allows more electricity to flow.
Online Equivalent				

The questions were written to correspond as closely as possible, without being clearly identical to participants. Consider question 1 from Table 3.4

In both cases, the subject of the question is increasing their total energy. The responses "A turtle is placed inside the box" and "Buy a Ferrari" both correspond to the *vis-viva* understanding of energy, where energy is a measure of the liveliness of an object. The responses "A smiley face is drawn on the side of the box" and "Get a job in the financial sector" both correspond to the *qi* understanding of energy in which energy is a measure of the ambition and happiness of the subject. The responses "The box is pushed off the edge of the table" and "Go for a run" both correspond to the *flux* understanding of energy, where energy is equated to motion. The remaining options increase the gravitational potential energy of the subject.

In addition to the simple, easily-parsed, attractive aesthetics, care needed to be taken that the online quiz displayed cleanly on both computers and smartphones. Given these demands, online quiz programs like Google Forms or SurveyMonkey would not be adequate, so the quiz was programmed completely from scratch using HTML, CSS for styling, and server-side Javascript to modify the page on the fly. The online quiz was placed at http://whatismyenergytype.com (and a copy is in Appendix 2) and should remain online through 2017. From the custom domain, to the formatting, to the design, every effort was made to ensure that participants are not jarred from their home cultures, nor signaled to switch to thinking like a scientist, when they answer the questions.

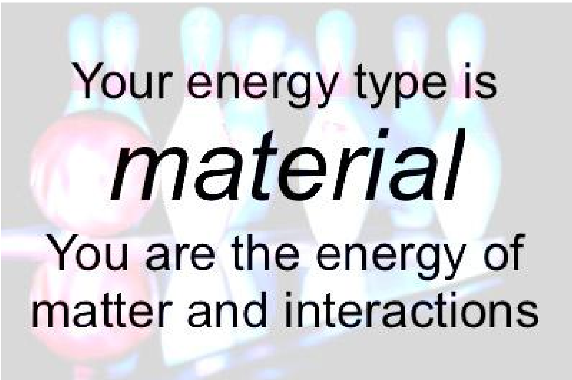
Several participants, and others who also took the online quiz, had questions about the mechanics of the quiz, and were curious why it didn't work exactly like the ones on Buzzfeed. Specifically, Buzzfeed's quizzes redirect to a new page with each question (and thus serve more ads) while this study's questions were all on one page. Because the participants so easily bought into the paradigm, it is likely that they were inhabiting their home cultures while undertaking the quiz, rather than thinking like physics students.

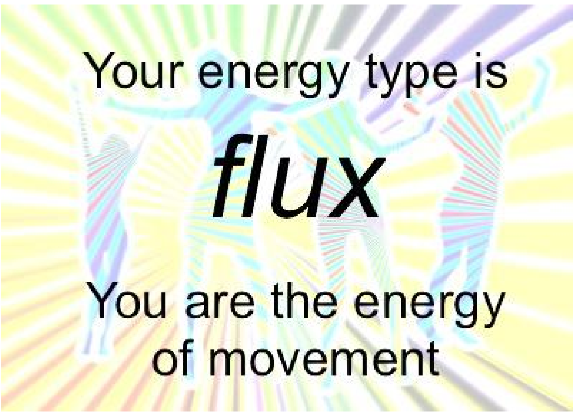
The online version of the quiz displays two items once all eight questions have been answered (see Table 3.5). The first item is a graphic that identifies the "energy type" (*vis-viva*, *flux*, *qi*, or the scientific *material*) that describes at least four of their answers. If none of these four understandings has more than three answers, the graphic says "mixed". The second item is an 8-digit code that identifies the participant's answers. A 1 represents the scientist's understanding of energy, 2 is *vis-viva*, 3 is *flux*, and 4 is *qi*. For example, a code of 11112211 means that the participant chose the scientific answer for all of the questions except the fifth and sixth, for which she chose the *vis-viva* response. The participants were asked to write down or email their 8-digit code, and give it to their teacher.

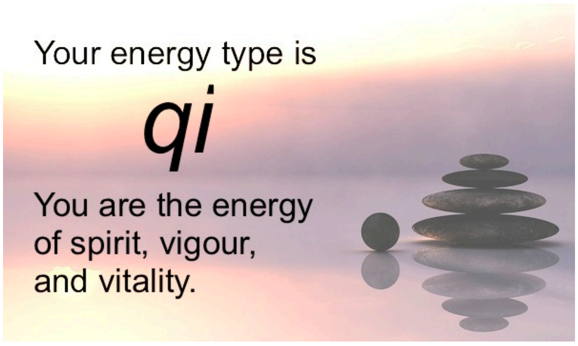
Although the online quiz gives responses, related to the energy concepts that are outlined earlier, it is important to note that these are not necessarily meaningful outcomes. The energy conceptions have not been explored theoretically, and there is no particular reason to believe that individuals tend to align with one or the other. However, since this is an online quiz, it was clear that the participants would need a ‘payoff’ for clicking the buttons, and so these graphics were created for that purpose.

Table 3.5.

Five possible responses for the online quiz, plus the code that is generated from the participants results







	**Your completion code is 42244314.** **(You may need to give this to your teacher)**

Each question was developed to specifically target the relevant concept. Because there isn't one correct answer, classical testing theory is not able to suggest much here. However, one goal -- that the answers are discriminable, and that the test discriminates between test-takers -- carries over. The questions were written to have four distinctly different, plausible, relevant answers. Participants who reported being unsure about their answers said that they felt multiple answers were possible, but never that multiple answers were identical. The question of discriminating participants will be addressed in the data analysis.

Once the two quizzes were developed, they were first shared with numerous experts for proofing and validation. The experts included a science teacher, a doctor, a software engineer, and a historian. No major problems were identified, but each provided constructive feedback in order to improve the wording of the questions and answers. As expected, the science teacher's results suggested a very strong orientation toward the scientific answers, the doctor and software engineer selected mostly scientific answers with a couple discrepancies, and the historian demonstrated an energy concept that was not particularly scientific.

The written quiz was known to be appropriate, as it was developed by the author, a teacher with a decade of experience creating these standard science assessments. However, the online quiz was a different matter. Thus, the online quiz was deployed to a class of 6th-grade students twice, at a 2-month interval, in order to determine whether the questions were comprehensible, and whether their answers would remain constant over time. 13 sets of responses were available from the first round, and 12 sets from the second. The results are in table 3.6. The rates at which the students chose the questions is approximately constant, suggesting that the results of this quiz are stable. The small differences shown in the data might be explained if the students learned a bit about energy in their science class, in which case the scientific answers should become more popular. The *vis-viva* understanding is typical for students of this age, and is often reinforced by well-meaning elementary school teachers who talk about the role of energy in the life sciences without being careful about what they mean, so it is not surprising that this has slightly increased as well. Thus, it is clear that the online quiz is appropriate and relevant for use.

Table 3.6.

Results from the deployment of the instrument to 6th-grade students

First Attempt			After Two Months		
Answer type	Number	Fraction	Answer type	Number	Fraction
Scientific	36	0.38	Scientific	43	0.41
vis-viva	28	0.29	*vis-viva*	35	0.34
flux	13	0.14	*flux*	13	0.13
qi	19	0.20	*qi*	13	0.13
total	96	1.00	total	104	1.00

3.4 Data from the instrument

The paired quizzes were applied to two classes of 11th-grade physics students. The students were enrolled in the International Baccalaureate Diploma Programme at the International School of Latvia. The students wrote the school quiz at school and, within the next week, were assigned to write the home quiz as homework. After excluding students who didn't complete both quizzes, a total of 27 samples were obtained.

The students' school quizzes were graded, and their codes from the online quiz were obtained. After this, the students were debriefed about the purpose of the experiment, and consent was obtained to use their results in this research. The students' responses are recorded in Appendix 6. One student did not complete the online quiz, so his results were omitted from further analysis. In a few cases, a student skipped a question on the classroom quiz. It was noted that the skipped questions appear to vary, and so including the rest of these students' responses is unlikely to bias the results.

Table 3.7.

Collected data from the instrument, where (a) is the scientific answer, (b) is *vis-viva*, (c) is *flux*, and (d) is *qi*

Participant	Energy Comprehension Test (classroom)								What is my Energy Type? (online)							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
1	a	a	a	a	a	a	a	c	a	a	a	a	a	a	a	a
2		a	a	b	a	a	a	a	c	a	a	d	b	d	a	b
3	c	a	a	a	a	a	a	c	c	c	a	a	b	d	a	a
4	c	a	c	a	a	a	a	c	a	a	c	a	b	d	a	a
5	a	a	a	a	a	a	a	c	c	a	b	b	c	a	a	a
6	b	a	a	c	a	b	c	b	c	a	a	b	a	d	a	a
7	c	a	c	d	a	c	c	c	c	c	c	b	b	c	a	a
8	a	a	a	a	a	b	a	d	a	a	a	a	a	a	a	a
9	c	a	c	d	a	c	c	b	c	b	d	b	a	c	a	d
10	c	a	b	a	a	b	a	b	a	a	d	b	b	d	a	a
11	a	a	a	c	a	a	a	b	a	c	a	b	a	a	a	a
12	a	a	a	a	a	a	a	c	c	a	c	b	b	d	a	a
13	c	a	c	c	a	a	b	c	a	a	a	c	b	c	a	a
14	a	a	a	a	a	d	b	c	a	c	a	a	b	d	a	a
15	c	a	c	a	b	a	c	d	a	a	c	a	b	a	a	d
16	b	a	c	c	c	b	a	a	c	c	c	b	b	a	d	a
17	b	a	c	a	a	a	a	b	a	d	c	d	a	c	a	b
18	a	a	a	a	a	b	a	d	a	a	a	b	a	a	a	a
19	c	a	d	d	d	a	c	b	c	a	d	b	b	c	a	a
20	c	c	c	a	b	b	a	c	a	c	c	d	b	c	a	a
21	c	a	d	b	b	a	a	b	a	a	c	b	b	a	a	a

22	c	b	a	a	d	a	b	c	c	c	d	b	b	c	a	a
23	c	d		c	a	d	c	d	a	b	c	b	b	a	a	a
24		a	a	a	a	c	a	c	c	a	c	a	a	a	d	a
25	c	a	a	b	a	c	c	c	a	a	c	a	b	d	a	a
26	c	a	a	c	c	a	a	a	a	a	a	b	b	c	a	c
27	c	a	c	c	b	c	a	d	c	a	c	b	b	a	a	a

3.4.1 Inferential statistics

In the first stage of analysis, the core question is whether different students have different types of border-crossing. These types of border-crossing can be seen in the data as described in Table 3.8. The ‘I Don’t Know’ students would be grouped in with the Outsiders in this categorization scheme.

Table 3.8.

Answer-type descriptions for four different border crossing types

Potential Scientists	will choose (a) and (a), the scientific answers, on both quizzes
Other Smart Kids	will choose (a) in school, and (b,c,d) at home
Outsiders	will choose (b,c,d) at school, and (b,c,d) at home
Inside Outsiders	will choose (b,c,d) at school, and (a) at home

Since there are four types of border-crossing, and 27 student responses, a contingency table with $4 \times 27 = 108$ entries can be constructed. In order to determine whether the two (categorical) variables are independent, a chi-squared test will be conducted. The null hypothesis is that border-crossing type is independent of the student, or, that different students do not have have different border-crossing types. The contingency table is presented in Table 3.9.

In a 4×27 contingency table, there are $(4 - 1) \times (27 - 1) = 3 \times 26 = 78$ degrees of freedom. At standard 95% confidence, this generates a critical value of $\chi^2_{crit} = 99.6$. The calculation of chi-squared from the data in Table 3.7 generates a value of $\chi^2_{calc} = 103.3$. Since $\chi^2_{calc} > \chi^2_{crit}$, the null hypothesis can be rejected. Thus, we claim that different students experience different types of border-crossing.

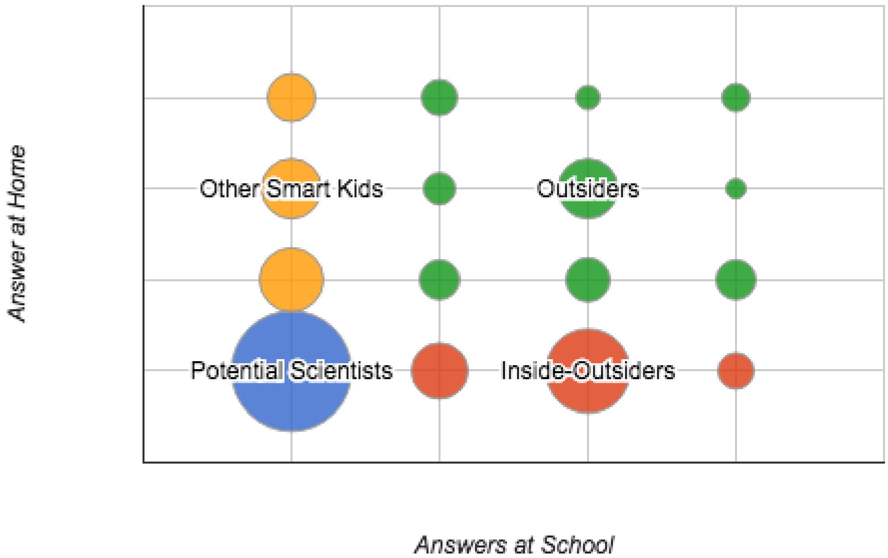
Table 3.9.

Contingency table for border-crossing types

Participant	Pot Sci	Outsider	Other Smart	Inside Outsider	Total
1	7	0	0	1	8
2	3	1	3	0	7
3	3	1	3	1	8
4	3	1	2	2	8
5	3	0	4	1	8
6	3	3	0	2	8
7	0	4	2	2	8
8	6	0	0	2	8
9	1	5	1	1	8
10	2	2	2	2	8
11	5	1	1	1	8
12	2	0	5	1	8
13	1	1	2	4	8
14	3	1	2	2	8
15	3	3	0	2	8
16	1	4	2	1	8
17	2	2	3	1	8
18	5	0	1	2	8
19	1	4	1	2	8
20	1	4	1	2	8
21	3	3	0	2	8
22	0	3	3	2	8
23	0	2	1	4	7
24	3	1	2	2	8
25	1	1	2	4	8
26	3	2	2	1	8
27	2	4	0	2	8
Total	67	53	45	49	214

Graph 3.1.

A bubble graph of responses to the main instrument. Each of 27 students contributed 8 responses. Answers (a) to (d) are found along the horizontal and vertical axes, so that (a) and (a) is the large bubble labeled "Potential Scientists". Bubble size corresponds to the number of responses.



One further advantage of creating this contingency table is that it allows us to quickly identify the border-crossing type of particular students. For example, students 1, 8, 11, and 18 answered at least 5 of the paired questions with the scientific answer for both. We could thus claim that these students are so-called "Potential Scientists". Indeed, three of these students have begun post-secondary studies in engineering, and the fourth is likely to do the same when she graduates this year. Student 9 is a good example of an "Outsider": she rarely studied, and generally did just enough work in her classes to satisfy her mother. Student 12, an "Other Smart Kid", has since enrolled in a top-tier liberal arts university, and is prospering in an environment where he can study broadly. Student 23, with four paired answers matching the "Inside Outsider" criteria, is a great example of the category: she reads popular science articles frequently at home, and is full of curiosity about scientific concepts, but is a rebel at heart and has traditionally struggled with authority. Other students show a mixture of border-crossing types, but for most a tendency in one direction can be seen from the data.

Chart 3.1 shows graphically the 214 responses. As promised in Table 3.8, the Potential Scientists are those who answered (a) -- the scientific answer -- on both the classroom and home tests. In this bubble chart, the area of the bubble is proportional to the number of responses. One interesting conclusion to observe here is that the Other Smart Kids were equally likely to choose among the three non-scientific responses at home. Meanwhile, their inverses, the Inside-Outsiders, seemed to preferentially chose *flux* when responding at school. Perhaps *flux* is perceived to be more scientific, and is thus a more attractive distractor.

3.4.2 Probabilistic model

Although the chi-squared test shows that border-crossing exists, it doesn't indicate to what extent border-crossing is responsible for the variation in the answers. In order to address this question, a probabilistic model was created. In the field of physics, this type of analysis is known colloquially as a "Monte Carlo" simulation because of the random nature of the input.

First, the model restricts responses to two types, (a) and (b) (ie: scientific and nonscientific), rather than the four in the tests, since the only question that matters for this analysis will be whether the response matches the scientific answer or not. Of the data used in the previous analysis, 232 of the 437 responses (53.1%) were (a). Thus, a model will be created in which a student's likelihood to answer (a) is given by $(53.1\ \pm c)$ % where c is a constant we wish to find.

This new probability will be calculated for both the home and school settings, and the plus-or-minus accounts for the fact that students might do better or worse. For example, an average Potential Scientist will have a $(53.1\ +\ c)$ %chance of answering scientifically at school (and at home, too). To account for the variation, a class of 100 students will be created, each randomly doing better or worse at home and school.

Here, and assumption is being made that cultural familiarity will result in a c% boost in the percentage of questions answered scientifically, and that cultural discomfort will result in a c% drop. For, example, imagine that $c\ =\ 10\%$. Then, a student will have a probability of answering (a) given by $(53.1\ \pm\ 10)$ % at home and $(53.1\ \pm\ 10)$ % at school. So student 1 (an Other Smart Kid) might have probabilities 63.1% and 43.1%, student 2 (an Inside Outsider) might have probabilities 43.1% and 63.1%, student 3 (an Outsider) might have probabilities 43.1% and 43.1%, and so forth. In the simulation, many such students will be created, and so the large number of students means that we will have approximately a quarter of each pair of probabilities.

The code used to create this analysis is available at https://repl.it/C5mb/4, and is located in Appendix 3. It is written in Python 3, using an online compiler. For a given value of c, it calculates the results of the paired classroom/online quizzes for an imaginary class of 28 students, with each student given a random border-crossing type. Then, it evaluates the value of chi-squared for that class, as was done in the previous analysis, for 100 such classes. It then takes those 100 values of chi-squared and calculates a mean value of chi-squared, and a standard deviation in this value.

The code was run for values of c between 0 and 0.3, and then Student's t was calculated for each of the values of chi-squared to determine whether which value of c resulted in a model that most closely matched the experimental results. The formula for this is:

$$t = \frac{mean\,\chi^2 - 103.3}{\left(\frac{std\,dev\,\chi^2}{0.5^{1000}}\right)}$$

where the 1000 represents the number of samples, and the 103.3 is the experimental value of chi-squared. The data for this analysis is presented in Table 3.10. The result is that a value of $c = 17\%$ is most similar to the experimental results.

Thus, this model suggests that the experimental pool was students where the ideal Potential Scientists and Other Smart Kids answered $(53.1 + 17)\% = 70\%$ of the questions in a scientific way at school, compared to the Outsiders and Inside Outsiders, who answered $(53.1 - 17)\% = 36\%$ of the questions in a scientific way, simply because of how they interacted with the culture of the physics classroom. This effect means that students with cultural predispositions toward science, or with stronger skills in managing border-crossings, will score nearly 100% higher than their peers. Clearly, cultural forces are strong and important!

Table 3.10.

Results of a probabilistic simulation of student results, assuming that border crossing provides a fractional advantage in answering questions scientifically given by c. The value of t compares the simulated result with the data obtained in the experiment, and thus c = 0.17 = 17% is preferred.

c	mean χ^2	standard deviation in χ^2	Student's t
0	81.49712889	11.5404567	-59.72158276
0.01	81.79478611	12.05788542	-56.37817652
0.02	81.6453599	11.90887333	-57.48040517
0.03	82.10923697	11.94605501	-56.07355586
0.04	82.98093996	12.11797187	-53.00326828

0.05	83.72471523	12.29419348	-50.33041622
0.06	84.11316905	12.14797379	-49.92502429
0.07	84.61571894	12.61020034	-46.83477247
0.08	86.3624913	12.94878967	-41.34425573
0.09	87.16133987	13.44488011	-37.93981484
0.1	89.78821353	12.97253511	-32.91779279
0.11	90.56795488	13.44507559	-29.92691516
0.12	92.18677204	13.7874296	-25.47089291
0.13	94.77246479	14.21456699	-18.95318788
0.14	96.93948131	13.68076493	-14.68370229
0.15	98.26898728	14.54896494	-10.91772574
0.16	100.8469416	14.62065672	-5.288376366
0.17	103.3769704	15.3634047	**0.1748960533**
0.18	106.2551893	15.83989513	5.915712908
0.19	109.8625149	16.11912371	12.89015022
0.2	112.8637248	16.24629924	18.63098245
0.21	117.1787008	16.85581199	26.05249975
0.22	119.6222309	16.83582553	30.67311689
0.23	123.303434	17.82394648	35.50375937
0.24	127.552528	18.76191527	40.89056186
0.25	132.3069774	19.3442671	47.43183822
0.26	136.0028613	19.49648114	53.05615155
0.27	139.9807297	20.64367977	56.20119646
0.28	145.2921255	20.26293339	65.54631356
0.29	149.5863702	21.11073351	69.34654949
0.3	156.4710069	21.41411226	78.53082282

RESULTS

This work has presented an argument for the existence of cultural border crossing for the physics classroom. At a 95% confidence level, for a sample of n=27, the identity of a student is not independent of their border-crossing type. Thus, the claim that different students experience different categories of border crossing is supported.

Of the 214 paired responses, 67 corresponded to the “Potential Scientist” form of border crossing. 45 were “Other Smart Kids”, 53 were “Outsiders”, and 49 were “Inside Outsiders”. Of the 27 participants, four could be identified as “Potential Scientists”, and in follow-up queries, these students acknowledged being interested in science, and were intended to pursue a career in science or engineering.

Two further students are clear examples of “Other Smart Kids”, as they have at least two more responses in that category than in any other. These two students, incidentally, have also chosen to pursue engineering, suggesting that they are continuing to work to overcome the cultural border between their home culture and the world of science. Five students received at least two more “Outsider” paired responses than any other. These students were generally lower-achieving in science, and planned to pursue careers in economics or related careers. One student fit the “Inside Outsider” criteria, and he was a clear example of the category. He found science fascinating, but struggled with language and had poor study habits. He is now pursuing engineering at university, fortunately; it seems that he has learned to navigate the tremendous cultural border.

Further, given the existence of this border-crossing, a simple probabilistic model shows that students who cross borders with ease receive a 17% increase in their ability to answer questions about energy with the scientific answer, while those who struggle experience a decrease by the same amount.

DISCUSSION

Implications and limitations

Taken at face value, these results suggest that successful border-crossers will experience a $17\% + 17\% = 34\%$advantage over unsuccessful border-crossers on assessments in their sciences classes simply due to cultural factors. Here, the orientation toward scientific understandings is seen by the science teacher as correctness on the assignment. This margin is often the difference between strong and weak grades, for example, between a score of 50% and 84%. However, it is not the intention of this work to claim that the majority of students' science grades are determined by culture. Instead, the 17% result should be seen as an upper-bound estimate of the advantage or disadvantage of an average student given no support in her learning.

One reason for the weakness of this result comes from precisely the same place as the power of the border crossing metaphor. It is a useful concept that covers a lot of different aspects, including strategies for academic success like study habits and parental support, the degree of informal learning that is experienced outside of school, and the student's intrinsic motivation. Saying that "Potential Scientists" have a 17% advantage in science assessments because of their home cultures conflates a plethora of underlying causes. Therefore, it is sufficient to remark that effective border crossing can provide a significant advantage for students, without needing to qualify or quantify that advantage.

The core result of this work is that border crossing is observed to exist in the physics classroom, as seen in the experiment conducted. Although the results are statistically and methodologically valid, there are limitations to the validity of this result. First, the limited number of participants (n=27) means that this work lacks the conviction of a study with a larger number of participants. The likelihood of a false positive result is larger with a small sample. Thus, to better establish the result, the author should -- and plans to -- continue the study with more students in the future.

Another possible concern is the relative generational and socioeconomic homogenity of the participant pool. Although the participants provide a good sampling of national, ethnic, religious, and and popular cultural alignments, they are all aged 16 to 18, and most are from the upper or upper-middle classes. On the issue of ages, no excuse can be more, nor is one needed. This study is about today's youth, and relevant for teachers today. If students' capacities in crossing borders evolves over time, this work will need to be revised. On the issue of wealth, it can only be acknowledged that this limitation to the research exists. It is possible that students from rich families are more likely to fall into the border crossing categorization scheme. However, this is unlikely: these children are equally children, experiencing the same bulk social, family, and cultural forces.

A subtle issue is the question of whether the two paired tests are actually assessing the same concepts. If they are not, the categorization and resulting analysis would be spurious. While this is possible, it is unlikely. During the validation process, the validators had very strongly-matching scores. The computer scientist, for example, chose the *flux* option twice in each set of eight questions, but these options matched between the paired questions. Likewise, the historian's scores exhibited a variety of non-scientific choices, but these were also stable. Furthermore, a small number of students took the online quiz in school, during a break between classes, instead of doing it at home. These students, still thinking as science students, chose the scientific responses overwhelmingly. Their results were not included in the analysis. These anecdotes make it clear that understandings of the energy concepts are stable for those who don't cross borders. Thus, the paired tests are probably addressing the same concepts effectively.

Acculturation and Enculturation

Aikenhead (1996) distinguishes between different ways students might experience different cultures in their schooling. The least desirable is via *assimilation*, where students are brought into a new culture by violently replacing their worldview with that of the new culture. The next step up is *enculturation*, where students are brought into a new culture using the familiar levers of education. For example, a teacher might expect his students to adopt scientific ways of knowing. We have seen that different categories of border-crossers would respond to such an expectation in different ways: "Other Smart Kids" might learn how to act as scientists in the classroom, while "Outsiders" might simply fail to meet the teacher's expectations. These two methods of cultural instruction are more likely to produce young adults with socially-desirable attitudes (like a generation of engineers), but risk disenfranchising children, especially those from minority, at-risk, or underrepresented cultural groups.

More acceptable is *autonomous acculturation*, where students are set up situations where they can adopt new cultures on their own, to whatever extent they are comfortable and using their own acquisition methods and tools. Similar are the so-called anthropological approaches, whereby students learn about cultures, rather than joining them directly. There are big differences between these four approaches to learning, yet this is an issue that isn't typically dealt with by teachers and curriculum developers.

Thinking about border-crossing brings this essential question to the forefront, where it ought to be. Asking teachers to look at the cultural border-crossing their students undertake will inevitably result in discussions about what sort of borders -- and immigration controls, to continue the analogy -- are acceptable and desirable in our schools. This research points out that students experience cultural border-crossing in different ways, and that this border-crossing can play a major role in student success at school. We are clearly overdue in focusing on cultural issues, especially *interstitiality* -- the space between cultures -- in our schools, and border crossing is a good tool to begin to approach that.

Critical pedagogy

Paolo Freire (1970) writes about violence between cultures as a force motivating his critical pedagogy. Rather than border crossing, he identifies "cultural invasion" as the core action: "an act of violence against the persons of the invaded culture" (152). Forcing students to cross cultural borders in their school could be considered a form of cultural invasion, especially if those students have home cultures that are orthonormal to the cultures of school, or the science classroom. Thus, from the perspective of critical pedagogy, border-crossing is suspect, and may lead to "cultural inauthenticity" (153) of the home cultures of students if it is not done with respect and care.

This theme has been picked up recently, especially in the areas of cross-cultural education of First Nations and Maori students in Canada and New Zealand. In Canada, Marie Batiste (2013) writes that, through education policies, governments use "vague notions of 'standards' and 'public good' to control what counts as knowledge, how this knowledge is diffused, and who benefits from it all" (96). In New Zealand, Michael Michie (2014) worries about educators who "do not cross the border" themselves, and may "maintain or even reinforce an essentialised cultural identity" (21).

The threat of cultural invasion is manifest, and may result in the subjugation of the lower classes or the domination of minority groups, with education as the weapon. Educators committed to social justice, thus, must carefully consider the role they are assuming, and the cultural actions they are undertaking. If they are enforcing policies of cultural assimilation or enculturation in their classrooms, they are guilty of perpetuating cultural warfare.

Border crossing gives educators a way to understand how their work impacts students' cultural experiences at school. If a teacher sees that many of her students are "Outsiders" or "Inside Ousiders", she might reflect on why her students are finding the border crossing from home to her science classroom to be so difficult. For example, the school's policies and rules might be alienating students -- if students are fighting a war against their teachers over the school dress code, they are unlikely to be able to muster the trust to cross the border into their teacher's science classroom.

On the other hand, if a teacher sees that many of her students are "Other Smart Kids" (or "I Don't Know" students), she might ask how she could align her teaching practices and expectations in a way that makes learning science more accessible for her students. For example, he may be teaching science in a way that requires the memorization and use of numerous equations, when students haven't yet mastered basic ideas of algebra.

A teacher might see a class with a large number of "Potential Scientists". These students will need challenges beyond the curriculum in order to stay engaged, but will work hard and get good grades even if they are not provided for.

Educators who can see students going through these border-crossings already exist: they are the sorts of teachers who look more closely at students, and care about them. However, it may take years or decades of careful observation, trust, and conversation for even a dedicated teacher to learn the difficulties his students are experiencing. This is especially true for cultural issues, since these are by nature difficult to articulate or recognize, particularly when the teacher and student don't share cultural backgrounds. By learning about the border crossing metaphor, teachers are given a valuable tool to help their students perform better in their physics class. But more importantly, with the border crossing metaphor, teachers can more readily empathize with, and understand, the difficulties through which their students go every day.

Further work should be directed in two directions. First, there is a need to determine whether the border crossing metaphor is useful in practice. Teachers should be taught how to think in terms of border crossing, and they should be observed and asked to reflect to determine whether this paradigm helps them to improve the educational experiences they provide for their students. For example, when teachers learn about border crossing, are they more sympathetic toward those students who come from dramatically different cultural backgrounds?

This approach will be particularly important for teachers who work cross-culturally, especially teachers from Western backgrounds who work in non-Western cultural settings such as the developing world, or with with First Nations or Aboriginal students in Canada or Australia. One good target for such a study would be volunteers who travel to developing countries to act as teachers. They could be taught the border crossing metaphor, and asked to keep a journal of their interactions with students. Frequent check-ins via telephone would allow the researcher to maintain a longitudinal record of the teacher's development as a cross-cultural worker. Action research such as this could provide good perspectives while also sharing the power border crossing metaphor with those who most need it.

Second, the present study could be expanded to accommodate for the limitations identified earlier. Specifically, the study could be enlarged to include multiple schools with a wider variety of socioeconomic audiences. Additionally, the same study could be conducted over several years to determine whether the border crossing metaphor is becoming more or less relevant over time. This approach has a methodological issue, however, in that Buzzfeed-style quizzes are rapidly falling out of fashion: in a few years, students might be unfamiliar with the medium, and the cultural familiarity they engender would be lost.

On a smaller scale and more informally, the instrument could be shared with teachers, so they can try it out for themselves. Hopefully, this proof-is-in-the-puddling approach would act as an effective advertisement for the border crossing metaphor.

CONCLUSION

The aim of this study was to determine whether border crossing exists for students entering the physics classroom. Based on a sample of n=27 at a 95% confidence level, a chi-squared test showed clearly that different students do fall into different border crossing categories. Therefore, subject to the limitations outlined above, border crossing does exist for the participants in this study. It can be reasonably extrapolated, therefore, that the answer to the research question for this work is that yes, border crossing does exist for students of the present generation of students.

Further, it has been shown that cultural factors may be responsible for a significant fraction of a student's success on school assessments. Specifically, participants were grouped into different categories of border-crossing. Using a probabilistic model, participants experienced a gain or loss of 17% against the mean depending on their border-crossing type.

This work suggests that teachers should be taught the border-crossing metaphor, and should seek ways to facilitate the border-crossing experience for their students. Educators might also use the border-crossing metaphor to reflect on how they are teaching cultures, including physics, in the schools.

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APPENDIX 1: RAW DATA FROM THE PRELIMINARY INSTRUMENT

Data

ID	*1*	*2*	*3*	*4*	*5*	*6*	*7*
D1	*1*	*1*	*2*	*1*	*1*	*2*	*1*
D2	*2*	*3*	*1*	*1*	*2*	*1*	*2*
D3	*1*	*2*	*2*	*1*	*2*	*1*	*2*
HS1	*4*	*3*	*4*	*1*	*4*	*4*	*1*
HP1	*4*	*3*	*4*	*3*	*4*	*4*	*3*
HS2	*4*	*1*	*4*	*2*	*1*	*2*	*3*
HP2	*4*	*2*	*2*	*2*	*1*	*2*	*4*
HS3	*4*	*4*	*4*	*4*	*4*	*2*	*2*
HP3	*4*	*3*	*3*	*3*	*4*	*2*	*4*
HS4	*3*	*3*	*3*	*2*	*3*	*2*	*3*
HP4	*3*	*4*	*3*	*3*	*3*	*2*	*3*
HS5	*3*	*2*	*1*	*1*	*3*	*3*	*2*
HP5	*3*	*2*	*1*	*4*	*3*	*3*	*3*
HS6	*2*	*2*	*4*	*1*	*2*	*4*	*4*
HP6	*1*	*2*	*4*	*1*	*2*	*4*	*4*
S1	*3*	*3*	*2*	*3*	*2*	*4*	*3*
S2	*2*	*2*	*2*	*2*	*2*	*2*	*2*
S3	*2*	*4*	*1*	*2*	*2*	*2*	*2*
S4	*3*	*3*	*3*	*3*	*3*	*3*	*3*
S5	*1*	*1*	*1*	*1*	*2*	*4*	*1*
S6	*2*	*2*	*1*	*4*	*2*	*1*	*1*

Codes

Question Number	Variable	Answer	Code
D1	Gender	Blank	0
		Female	1
		Male	2
D2	Nature of Relationship	Blank/Unknown/Other	0
		Mother	1
		Father	2

		Grandparent	3
D3	Translation	Blank	0
		No	1
		Yes	2
H1S	Home Question 1 Student Answer	Blank	0
		Only the green plants	1
		Only the red smoke	2
		Neither	3
		Both	4
H1P	Home Question 1 Parent Answer	Blank	0
		Only the green plants	1
		Only the red smoke	2
		Neither	3
		Both	4
H2S	Home Question 2 Student Answer	Blank	0
		Dog strong (motion)	1
		Dog strong (mass)	2
		Human strong	3
		Equal	4
H2P	Home Question 2 Parent Answer	Blank	0
		Dog strong (motion)	1
		Dog strong (mass)	2

		Human strong	3
		Equal	4
H3S	Home Question 3 Student Answer	Blank	0
		Gravity	1
		Push force	2
		Movement energy	3
		Friction	4
H3P	Home Question 3 Parent Answer	Blank	0
		Gravity	1
		Push force	2
		Movement energy	3
		Friction	4
H4S	Home Question 4 Student Answer	Blank	0
		Heat rises	1
		Heat quicker	2
		Cold quicker	3
		Iron colder	4
H4P	Home Question 4 Parent Answer	Blank	0
		Heat rises	1
		Heat quicker	2
		Cold quicker	3
		Iron colder	4

H5S	Home Question 5 Student Answer	Blank	0
		Electricity not used	1
		Different speeds	2
		Equal flow	3
		Wire unnecessary	4
H5P	Home Question 5 Parent Answer	Blank	0
		Electricity not used	1
		Different speeds	2
		Equal flow	3
		Wire unnecessary	4
H6S	Home Question 6 Student Answer	Blank	0
		Larger (much)	1
		Larger (bit)	2
		Smaller	3
		Same	4
H6P	Home Question 6 Parent Answer	Blank	0
		Larger (much)	1
		Larger (bit)	2
		Smaller	3
		Same	4
S1	School Question 1	Blank	0
		Releasing	1

		Eaten	2
		Light as carrier	3
		Intrinsic property	4
S2	School Question 2	Blank	0
		Equal forces	1
		Forward car	2
		Backward car	3
		Other	4
S3	School Question 3	Blank	0
		Unbalanced forces	1
		Balanced forces	2
		Gravity/Spring unbalanced	3
		Other	4
S4	School Question 4	Blank	0
		Cold flows	1
		Heat flows	2
		Both	3
		Heat rises	4
S5	School Question 5	Blank	0
		Electrons used up	1
		Electricity not used	2

		Safety	3
		Equal flow	4
S6	School Question 6	Blank	0
		Weightless fall	1
		Reads weight	2
		Reads less but not zero	3
		Other	4

APPENDIX 2: SOURCE CODE FOR THE ONLINE QUIZ

HTML code for the web site:

```
<!DOCTYPE html>
<html>
<head>
<title>What type of energy are you?</title>
  <link rel="stylesheet" href="index.css">
  <script src="index.js"></script>
</head>
<body>

<div class="everything">
  <h1>Energy Type Quiz</h1>
  <img src="/imgs/feelingdownq.jpg"/>
  <div class="eachtable" data-questionNumber="1">
    <div class="eachrow">
      <div class="eachcell">
        <input type="image" src="/imgs/feelingdown3.jpg"
value="3" onclick="setAnswer(this)">
      </div>
      <div class="eachcell">
        <input type="image" src="/imgs/feelingdown1.jpg"
value="1" onclick="setAnswer(this)">
      </div>
    </div>
    <div class="eachrow">
      <div class="eachcell">
        <input type="image" src="/imgs/feelingdown2.jpg"
value="2" onclick="setAnswer(this)">
      </div>
      <div class="eachcell">
        <input type="image" src="/imgs/feelingdown4.jpg"
value="4" onclick="setAnswer(this)">
      </div>
    </div>
```

```
  </div>
  <img src="/imgs/powerq.jpg"/>

  <div class="eachtable" data-questionNumber="2">
    <div class="eachrow">
      <div class="eachcell">
        <input type="image" src="/imgs/power1.jpg" value="1"
onclick="setAnswer(this)">
      </div>
      <div class="eachcell">
        <input type="image" src="/imgs/power4.jpg" value="4"
onclick="setAnswer(this)">
      </div>
    </div>
    <div class="eachrow">
      <div class="eachcell">
        <input type="image" src="/imgs/power3.jpg" value="3"
onclick="setAnswer(this)">
      </div>
      <div class="eachcell">
        <input type="image" src="/imgs/power2.jpg" value="2"
onclick="setAnswer(this)">
      </div>
    </div>
  </div>

  <img src="/imgs/carhillq.jpg"/>

  <div class="eachtable" data-questionNumber="3">
    <div class="eachrow">
      <div class="eachcell">
        <input type="image" src="/imgs/carhill3.jpg"
value="3" onclick="setAnswer(this)"  >
      </div>
      <div class="eachcell">
        <input type="image" src="/imgs/carhill2.jpg"
value="2" onclick="setAnswer(this)">
```

```
      </div>
    </div>
    <div class="eachrow">
      <div class="eachcell">
        <input type="image" src="/imgs/carhill4.jpg"
value="4" onclick="setAnswer(this)">
      </div>
      <div class="eachcell">
        <input type="image" src="/imgs/carhill1.jpg"
value="1" onclick="setAnswer(this)">
      </div>
    </div>
  </div>

    <img src="/imgs/vegq.jpg"/>

  <div class="eachtable" data-questionNumber="4">
    <div class="eachrow">
      <div class="eachcell">
        <input type="image" src="/imgs/veg2.jpg" value="2"
onclick="setAnswer(this)">
      </div>
      <div class="eachcell">
        <input type="image" src="/imgs/veg1.jpg" value="1"
onclick="setAnswer(this)">
      </div>
    </div>
    <div class="eachrow">
      <div class="eachcell">
        <input type="image" src="/imgs/veg3.jpg" value="3"
onclick="setAnswer(this)">
      </div>
      <div class="eachcell">
        <input type="image" src="/imgs/veg4.jpg" value="4"
onclick="setAnswer(this)">
      </div>
    </div>
```

```
  </div>
    <img src="/imgs/friendq.jpg"/>

  <div class="eachtable" data-questionNumber="5">
    <div class="eachrow">
      <div class="eachcell">
        <input type="image" src="/imgs/friend4.jpg" value="4"
onclick="setAnswer(this)">
      </div>
      <div class="eachcell">
        <input type="image" src="/imgs/friend2.jpg" value="2"
onclick="setAnswer(this)">
      </div>
    </div>
    <div class="eachrow">
      <div class="eachcell">
        <input type="image" src="/imgs/friend3.jpg" value="3"
onclick="setAnswer(this)">
      </div>
      <div class="eachcell">
        <input type="image" src="/imgs/friend1.jpg" value="1"
onclick="setAnswer(this)">
      </div>
    </div>
  </div>

  <img src="/imgs/ballq.jpg"/>

  <div class="eachtable" data-questionNumber="6">
    <div class="eachrow">
      <div class="eachcell">
        <input type="image" src="/imgs/ball3.jpg" value="3"
onclick="setAnswer(this)">
      </div>
      <div class="eachcell">
        <input type="image" src="/imgs/ball4.jpg" value="4"
onclick="setAnswer(this)">
```

```
      </div>
    </div>
    <div class="eachrow">
      <div class="eachcell">
        <input type="image" src="/imgs/ball1.jpg" value="1"
onclick="setAnswer(this)">
      </div>
      <div class="eachcell">
        <input type="image" src="/imgs/ball2.jpg" value="2"
onclick="setAnswer(this)">
      </div>
    </div>
  </div>

    <img src="/imgs/sleepq.jpg"/>

  <div class="eachtable" data-questionNumber="7">
    <div class="eachrow">
      <div class="eachcell">
        <input type="image" src="/imgs/sleep3.jpg" value="3"
onclick="setAnswer(this)">
      </div>
      <div class="eachcell">
        <input type="image" src="/imgs/sleep1.jpg" value="1"
onclick="setAnswer(this)">
      </div>
    </div>
    <div class="eachrow">
      <div class="eachcell">
        <input type="image" src="/imgs/sleep4.jpg" value="4"
onclick="setAnswer(this)">
      </div>
      <div class="eachcell">
        <input type="image" src="/imgs/sleep2.jpg" value="2"
onclick="setAnswer(this)">
      </div>
    </div>
```

```
  </div>
    <img src="/imgs/iphoneq.jpg"/>

  <div class="eachtable" data-questionNumber="8">
    <div class="eachrow">
      <div class="eachcell">
        <input type="image" src="/imgs/iphone1.jpg" value="1"
onclick="setAnswer(this)">
      </div>
      <div class="eachcell">
        <input type="image" src="/imgs/iphone2.jpg" value="2"
onclick="setAnswer(this)">
      </div>
    </div>
    <div class="eachrow">
      <div class="eachcell">
        <input type="image" src="/imgs/iphone3.jpg" value="3"
onclick="setAnswer(this)">
      </div>
      <div class="eachcell">
        <input type="image" src="/imgs/iphone4.jpg" value="4"
onclick="setAnswer(this)">
      </div>
    </div>
  </div>

  <p id="result"></p>
  <p>Web page by Danny. Image <a
href="/image_credits.html">credits</a>.</p>
  <p> </p>
</div>
</body>
</html>
```

CSS code for the website:

```
body {
  font-family: "Helvetica, Arial, sans-serif";
  font-size: 14px;
  max-width: 100%;
}

img {
  margin-bottom: 20px;
}

div span {
  margin: 10px;
}

div img {
  text-align: left;
}

input {
  background: #eee;
  border: 1px solid #ddd;
  padding: 20px 20px;
  margin-bottom: 10px;
  margin-right: 10px;
  color: white;
  font-size: 14px;
  font-family: Helvetica, Arial, Sans-Serif;
  text-decoration: none;
}

input:hover {
 background: #ffff70;
}

input:focus {
```

```css
  background: #3399ff;
}

.Selected {
  background: #3399ff;
}
.everything {
  height: 100%;
  width: 600px;
  display: block;
  text-align: center;
  margin: 0 auto;
}

.eachtable {
  width: 100%;
  display: table;
  margin-bottom: 50px;
  text-align: center;
  margin-left: auto;
  margin-right: auto;
}

.eachrow {
  display: table-row;
  text-align: center;
}

.eachcell {
  display: table-cell;
  text-align: center;
}

.result {
  font-size: large;
}
```

Javascript code for the website:

```
// Store the answers for all the questions here.
var answers = [0,0,0,0,0,0,0,0];

window.onload = function() {
  for(var i=0; i < 8; i++) {
    answers[i] = 0;
  }
};

function setAnswer(inputElement) {
  var divContainer = inputElement.parentNode.parentNode.parentNode;

  // set answersto include this choice
  var questionNumber =
Number(divContainer.getAttribute("data-questionNumber"));
  answers[questionNumber-1] = Number(inputElement.value);

  // unselect all the other answers, then select only the choice
  var inputElements = divContainer.getElementsByTagName("input");
  for(var i in inputElements) {
    inputElements[i].className = "";
  }
  inputElement.className = "Selected";

  var checkifdone = 1;
  for (var j=0; j<8; j++) {
    checkifdone = checkifdone * answers[j];
  }
  if (checkifdone !== 0) {
    getScores();
  }
}

function getScores() {
  var numcode = "";
```

```
  var scores = [0,0,0,0,0];
  for(var i=0; i < 8; i++) {
    numcode += answers[i].toString();
    scores[answers[i]]++;
  }

  var resimg = "";
  if (scores[1] > 3) {
    resimg = "/imgs/result_material.jpg";
  } else if (scores[2] > 3) {
    resimg = "/imgs/result_visviva.jpg";
  } else if (scores[3] > 3) {
    resimg = "/imgs/result_flux.jpg";
  } else if (scores[4] > 3) {
    resimg = "/imgs/result_qi.jpg";
  } else {
    resimg = "/imgs/result_mixed.jpg";
  }
  var outputstring = "<img src=\"" + resimg + "\"/>" + "<p><h2>Your
completion code is " + numcode + ".<br>(You may need to give this
to your teacher)</h2></p>";

  document.getElementById("result").innerHTML = outputstring;
}
```

APPENDIX 3: PYTHON CODE FOR THE PROBABILISTIC MODEL

```
import random
c = 0.1
iter = 100
totsSums = []
chiSqs = []

for k in range (0, iter):
 cats = [[0,0,0,0] for j in range (0,28)]
 tots = [0,0,0,0]
 pres = [[0,0,0,0] for j in range (0,28)]

# cats is PotSci (aa), Outsider (bb), OtherSmart (ab), InsOut
(ba)   in (TestType)

 for j in range (0,28):

# using the weighting function cFactor, calculate sample
student responses for test & type

     test = []
     type = []

     cFactor1 = 232 / 437 + c * ( round(random.random()*2) -
1)
     for i in range (0,8):
          if random.random() < cFactor1:
               test.append("a");
          else:
               test.append("b");

     cFactor2 = 232 / 437 + c * ( round(random.random()*2) -
1)
     for i in range (0,8):
          if random.random() < cFactor2:
               type.append("a");
```

```
                else:
                      type.append("b");

     # Compile these student responses into a row on the
actual/category value matrix

           for i in range (0,8):
                if test[i] == "a":
                      if type[i] == "a":
                           cats[j][0] += 1
                      else:
                           cats[j][2] += 1
                else:
                      if type[i] == "a":
                           cats[j][3] += 1
                      else:
                           cats[j][1] += 1
      # Column sums

      for j in range (0,28):
           tots[0] += cats[j][0]
           tots[1] += cats[j][1]
           tots[2] += cats[j][2]
           tots[3] += cats[j][3]

      grandTot = tots[0] + tots[1] + tots[2] + tots[3]

     # Calculate the predicted value matrix

      for j in range (0,28):
           for i in range (0,4):
                pres[j][i] = 8 * tots[i] / grandTot

     # Now, with the category value matrix and the predicted value
matrix, calculate chi^2

      chiSquared = 0
```

```
    for j in range (0,28):
        for i in range (0,4):
            chiSquared += ( pres[j][i] - cats[j][i] )**2.0 /
pres[j][i]

    totsSums.append(tots)
    chiSqs.append(chiSquared)

print(totsSums)

# Calculate means and errors for the tots and chi^2 terms

chiSqMean = sum(chiSqs) / iter
chiSqVar = 0
for k in range (0, iter):
    chiSqVar += (chiSqs[k] - chiSqMean)**2.0
chiSqStdDev = ( chiSqVar / (iter - 1) )**0.5

print(chiSqMean, chiSqStdDev)

totsMean = [0,0,0,0]
totsVar = [0,0,0,0]
totsStdDev = [0,0,0,0]
for i in range (0,4):
    for k in range (0, iter):
        totsMean[i] += totsSums[k][i]
    totsMean[i] = totsMean[i] / iter
    for k in range (0, iter):
        totsVar[i] += (totsSums[k][i] - totsMean[i])**2.0
    totsStdDev[i] = ( totsVar[i] / (iter - 1) )**0.5

print(totsMean, totsStdDev)
```

Master's paper “The cultural border crossing model applied to the physics classroom” elaborated in the Faculty of Pedagogy, Psychology and Art at the University of Latvia.

Herewith I confirm by putting my signature that the research has been conducted individually, as well as the fact that only the indicated sources of literature have been used in the paper and that the electronic copy of the paper corresponds to the printout.

Author: (personal signature) Daniel Doucette

I recommend/do not recommend the paper for defense

Advisor: professor Dr. paed. Dainuvīte Blūma (personal signature) 17.01.2017.

Opponent:

Paper submitted in the Department of Education Sciences on 17.01.2017.

Person authorized by the dean:

Paper has been defended in the session of the Commission on Master's Graduation Examination

27.01.2017.

Secretary of the Commission: