SOCIALLY CONSCIOUS SOFTWARE DEVELOPMENT A CASE STUDY

By

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ABSTRACT

What does it mean for software to be socially conscious? How can developers make software that avoids negative social consequences? This thesis seeks to answer these questions. Technology does not usually grapple with social or cultural divisions. When social identity is part of the technology's subject matter, additional care must be taken to developing content in a way that does not exclude any particular group of users. The Darwin game is one such case. Initial work by our NSF Triple Helix team suggested that underrepresented students resist learning about evolution due to the associations with racism. The game is a teaching tool that hopes to teach the concepts of the theory of evolution while also raising the question of Charles Darwin's abolitionist ties, with the intentions of keeping underrepresented students from feeling excluded from science and challenging the misconception of Darwin as a racist scientist. We hypothesized that exposing these connections would make students more receptive to the lesson. This game is but one of many instances in which special considerations have been taken to make STEM (science, technology, engineering, and math) material more inclusive. This thesis will discuss underrepresented groups in computing and software development, explore several of the existing approaches to teaching sensitive material, explain some of the issues encountered while building the Darwin game, and present some initial reactions from students.

CHAPTER 1
INTRODUCTION

How can we generalize the idea of promoting inclusivity and extend it to tools for potentially offensive topics? Is there a formulaic way to increase participation and students' feelings of belonging in the classroom without over-tailoring the approach to a small subgroup? This thesis explores existing attempts to do so in several steps.

First, in order to solve these problems, in addition to identifying the problem, we must identify the audience for whom we are attempting to solve the problem. In the case of this thesis, we are exploring a solution to increasing STEM participation for underrepresented groups, which means we must clearly define the members of these groups.

Next, we explore several existing approaches to increasing participation in STEM and classify them using various measures, including the target group, how the approach attempts to bridge the gap between students and material, and the specificity of the approach.

Finally, I introduce the Darwin game. In his essay "In the Name of Darwin", Daniel Kevles explains how Charles Darwin's ideas came to be used to support racism and classism. "Some supporters of Darwin's theory of evolution have misapplied the biological principles of natural selection – 'survival of the fittest' – to the social, political, and economic realms" [1]. Thus arose "social Darwinism". This misappropriation of Darwin's theory has led to the idea that Darwin himself was racist. The fact that the theory of evolution was misused to support racism has the potential to make students feel unwelcome in the classroom, and this implicit exclusion is thought to be a contributing factor to the underrepresentation of minority students in STEM fields.

The Darwin game is an attempt to remedy this problem. Currently being developed at RPI, the game is a multipart project that teaches users about Charles Darwin's personal history in addition to his scientific discoveries. The desire to build the game stemmed from a dearth of awareness about the abolitionist ties in

Darwin's family and, as a result, the potential for Darwin's own beliefs.

The Darwin game has two completed stages with a third currently being built. In the first stage, shown in Figure 1.1, users pull segments off a ladder, representative of monogenism, the view that "[r]aces have declined to different degrees, whites least and blacks most" [3]. These ladder segments are then used to build a tree, corresponding to Darwin's tree of life, with the root of the tree being an image of a Neanderthal and the branches images of peoples of different races. While completing this stage, the user receives input from Darwin, who references some of his family members and their opinions on the origins of humanity as we know it. This part of the game sets the stage for the remaining parts, where we use the same framework to show that animals have common ancestors. In addition to introducing the student to the tree structure integral to Darwin's theory, this portion of the game shows a side of Darwin not seen in science curricula, a perspective that has the potential to discontinue the association of evolution with racism.

After presenting existing approaches to this issue, the Darwin game is analyzed in the context of these approaches. I will also discuss some of the issues specific to the game and how the game was received during initial testing.

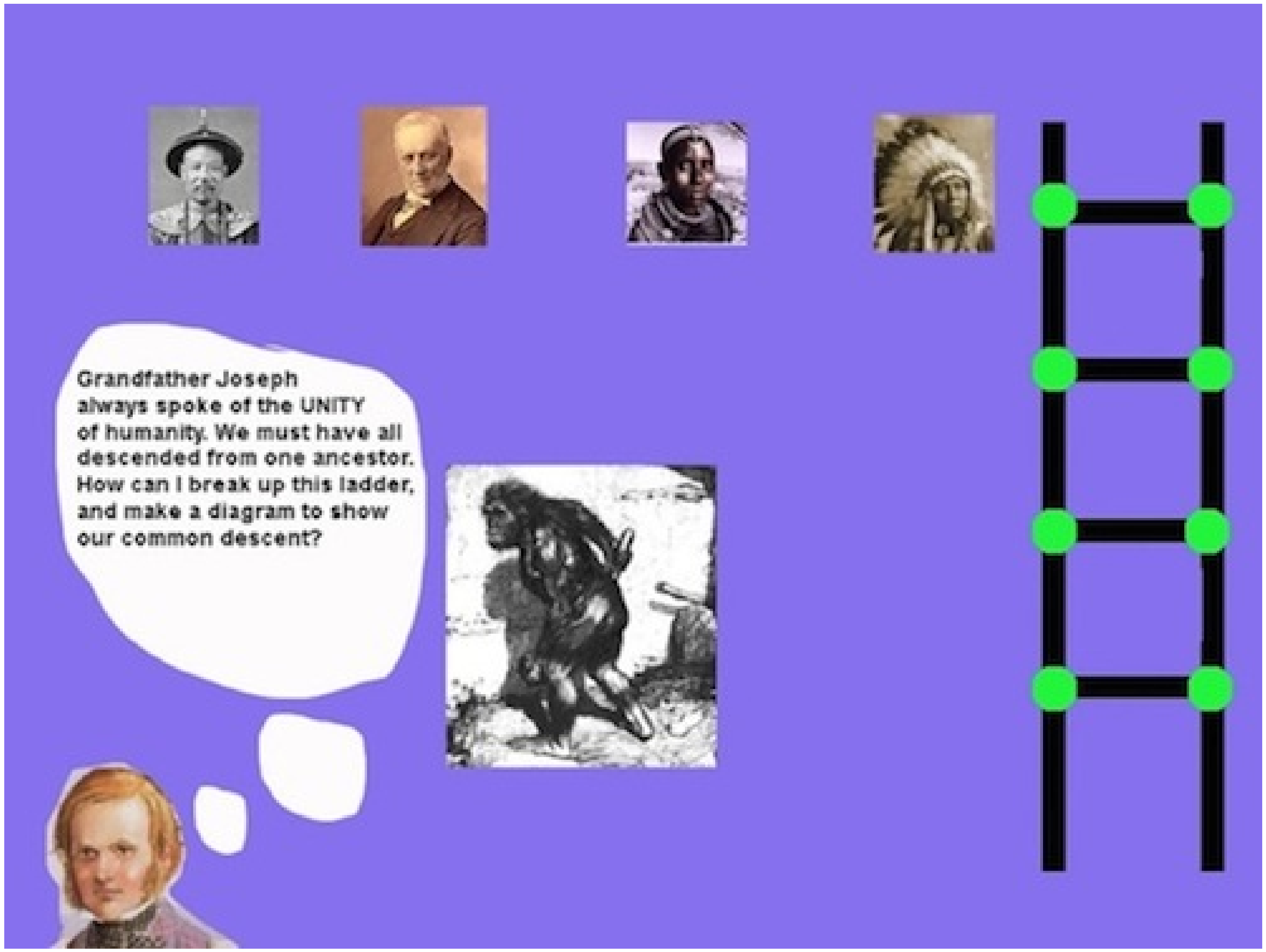

Figure 1.1: The interface for the first stage of the Darwin game [2]

CHAPTER 2
UNDERREPRESENTED GROUPS IN COMPUTING

According to the NSF, underrepresented groups in STEM fields are groups that "constitute smaller percentages of science and engineering degree recipients and of employed scientists and engineers than they do of the population" [4]. Based on this definition, the following groups are underrepresented: "women, persons with disabilities, and three racial/ethnic groups - blacks, Hispanics, and American Indians" [4].

How did these groups come to be underrepresented? There are several contributing forces to this problem. Several authors identify "community forces" and "noneconomic factors" [5] [6]. Ogbu defines community forces as "the way the minorities perceive and respond to schooling as a consequence of their treatment", noting that "responses are also affected by how and why a group became a minority" [5]. He also identifies three minority groups, "autonomous, voluntary (immigrant), and involuntary (nonimmigrant) minorities", and states that "[t]here are no non-white autonomous minorities in the United States", so neither his paper nor this thesis discusses autonomous minorities [5]. Where "[v]oluntary (immigrant) minorities are those who have more or less willingly moved to the United States because they expect better opportunities (better jobs, more political or religious freedom) than they had in their homelands or places of origin", "[i]nvoluntary (nonimmigrant) minorities are people who have been conquered, colonized, or enslaved" [5]. Eglash et al. cite "noneconomic factors", of which there are two [6]. The first of these is the myth of "cultural determinism", the idea that to do well academically is a betrayal of one's peers and a breaking of cultural ties. Fryer and Torelli found an inverse correlation between high academic performance and social status for both African-American and Hispanic students, with their study showing a decrease in social status at a 3.5 grade-point-average for African-American students and at a 2.5 for Hispanic students [7]. The second factor is the myth of "genetic determinism" (also called "biological" determinism by Gould), which is the notion that "the social and economic differences between human groups...arise from inherited, inborn distinctions" [3]. In a school setting, this would mean that differing levels of performance between students could be linked to their ethnic identity. These two concepts help to explain the race gap in STEM fields, shown in Table 2.1. In constructing this table, I attempted to use information from the 2010 census that classified individuals as belonging to one race[1]. As a result, the categories following "Hispanic or Latino" do not include those individuals who identified themselves as being of Hispanic origin and belonging to another race.

Table 2.1: American Population and STEM Workforce by Race [8] [4]

Race	**Percent of Population**	**Percent of STEM Workforce**
Hispanic or Latino	16.3	6.7
Black or African-American	14.6	6.0
American Indian or Alaskan Native	0.9	0.3
Native Hawaiian or Other Pacific Islander	0.2	0.3

When students internalize the myth of genetic determinism, it affects their academic performance. The idea of "stereotype threat" has been shown to affect students in the cases of both race and gender [9]. A study by Steele and Aronson showed that when African-American study subjects were told that a test was "diagnostic of intellectual ability", they performed at a lower level than subjects who were not given this information [9]. The same phenomenon was observed in a later study, dealing with gender differences instead of racial differences [10]. Table 2.2 highlights the gender gap.

[1]For the 2010 Census, a new instruction was added immediately preceding the questions on Hispanic origin and race, which was not used in Census 2000. The instruction stated that "For this census, Hispanic origins are not races" because in the federal statistical system, Hispanic origin is considered to be a separate concept from race. However, this did not preclude individuals from self-identifying their race as "Latino", "Mexican", "Puerto Rican", "Salvadoran", or other national origins or ethnicities; in fact, many did so [8].

Table 2.2: American Population and STEM Workforce by Gender [11] [4]

Gender	Percent of Population	Percent of STEM Workforce
Male	49.2	55.4
Female	50.8	44.6

Another potential explanation for this underrepresentation is a lack of accessibility to materials. While this can largely be categorized as an economic factor, it is sometimes the case that the materials simply don't exist, as in the case of materials for individuals with disabilities. The 1998 amendment of Section 508 of the Rehabilitation Act made technology more accessible to individuals with disabilities. "[I]n 1998, Congress amended Section 508 of the Rehabilitation Act (Section 508) to require federal agencies to ensure that the electronic and information technology (EIT) they procure, develop, maintain, and use is accessible to people with disabilities" [12]. Table 2.3 shows the percentage of Americans with a disability and their representation in STEM fields.

Table 2.3: American Population and STEM Workforce by Disability Status [13] [4]

Disability Status	Percent of Population[2]	Percent of STEM Workforce
With a Disability	18.7	7.5
Without a Disability	81.3	92.5

Prior to this amendment, approximately 19% of the population was being underserved and had no way of accessing materials available on the Internet. What must be stressed is that this change only affected government websites. This does not account for the vast majority of web content.

In addition to requiring that federal web materials be available to people with disabilities, Section 508 "requires the Attorney General to submit...reports...regarding

[2]This brief accounts only for the noninstitutionalized population, with a total of 303,858,000, where the briefs on race and gender report the total as 308,745,538.

the state of federal department and agency compliance with Section 508" [12]. In 2000, the first of these reports was released. In 2012, another report was issued regarding the progress of the implementation of the amendment. The increase in Section 508 compliance is shown in Table 2.4.

Table 2.4: Government Agencies' Incorporation of Section 508 Requirements [14] [12]

Does the agency use language requiring Section 508 compliance in EIT procurement?	**Percentage of Agencies in 2000[3]**	**Percentage of Agencies in 2012**
Yes	60.7	92.3
No	39.3	7.7

One reason the amendment to Section 508 was able to be implemented quickly and successfully is that the target audience for the amendment can be clearly identified. "An individual with a disability is a person who: [h]as a physical or mental impairment that substantially limits one or more major life activities; [h]as a record of such an impairment; or [i]s regarded as having such an impairment" [15]. The specificity of this definition allows solutions to the problem of accessibility to also be clearly defined.

Gender, in a manner similar to disability, can be described in ways that emphasize difference. In this way, at least, the problem of gender underrepresentation is made simpler by the ability to identify the target audience. The larger challenge, then, lies with bringing students who would be considered underrepresented with regard to race into STEM fields, because where proposed solutions to gender underrepresentation focus on differences in motivation, proposed solutions to racial underrepresentation focus on equality. As shown by the note in the 2010 census, race can be categorized many different ways, and an individual need not be defined exclusively by one label or another. Is there a way to avoid catering technologies

[3] In the report released in 2000, the results did not differentiate in all cases between seldom or never using language to require compliance [14]. For the purposes of this table, half of the cabinet-level and large agencies that reported seldom or never were taken as never.

to each of these different possibilities? The next chapter addresses this question by analyzing the specificity of several existing approaches.

CHAPTER 3
AN ANALYSIS OF APPROACHES TO INCREASING INCLUSIVITY AND PARTICIPATION IN STEM

Many of the attempts to bring underrepresented students into STEM fields rely on cultural ties. When constructing these teaching tools, developers must be sure to handle this material in a way that does not cause offense. Qi and Boyle describe four categories, which they call dimensions, of potentially culturally sensitive factors of learning tools: knowledge, pedagogy, access, and technology [16]. For the purposes of this thesis, we are primarily concerned with the access dimension, which deals with content and user interface.

The first approach we will examine is the CSDTs, or Culturally Situated Design Tools. The CSDTs make an attempt at "translating", or "modeling indigenous systems with a Western (i.e., mainstream, academic) mathematical representation" [18]. Currently, there are CSDTs that take mathematical principles from African, African American, Native American, and Latino cultures. By highlighting the math present in students' heritage, CSDTs take an "anti-primitivist" stance and show students that math appears in every culture and in myriad forms [18]. Through presenting this anti-primitivist view, CSDTs combat the myths of genetic and cultural determinism. Genetic determinism is disproven because these mathematical principles are being pulled from existing heritage phenomena. Cultural determinism is disproven more subtly. Students are making designs on the computer, an activity that does not belong to any particular group. There are also tools that pull from "youth subculture", with programs focused on graffiti, skateboarding, and breakdancing [18]. One of the drawbacks with this approach with regards to generality is that there is a subset of tools for each underrepresented racial group. While this does not explicitly limit users to any subset of the tools, the cultural identifiers used in the CSDTs, like braiding and beading, have no analogue in other cultures. This, however, has not deterred students from using tools to which they have no heritage tie. In fact, in studying students using tools inspired by other cultural backgrounds, the creators of the CSDTs observed patterns they had not seen from the target group. “We have seen several African American students from low-income urban areas use the VBL to write their initials, like the graffiti tags - a design not seen with any Native American, white, or Latino students to date” [18]. In preliminary evaluations of the CSDTs, the tools appeared to achieve their goal as minority students’ positive attitudes toward information technology careers increased after use of the CSDTs [18].

Next, we will look at the AADMLSS (African-American Distributed Multiple Learning Styles System) City Stroll [19]. As noted in *Culturally Responsive Computing*, this approach differs from the CSDTs in that where the CSDTs seek to engage students mainly through a heritage connection, AADMLSS attempts to engage students based on their vernacular culture [6]. This system uses an avatar to help the student interact with a virtual neighborhood, where the avatar engages in several activities, such as purchasing a candy bar from a store and using algebra to determine the price of the candy. The virtual neighborhood acts as an instruction environment, but the creators of the tools realize that “[p]ractice is required to become good at any undertaking”, so there is a practice environment as well [19]. After completing the practice section, the student is given an assessment. The student moves through the virtual neighborhood by passing these assessments. As the name suggests, the tool focuses on African-American students and the virtual environment that students explore is constructed specifically for this audience, described by the creators as “a typical urban environment that most African-American kids would recognize” [19]. If students were given the option to construct an avatar, this approach could be generalized and used for any student group in an urban setting.

Both of the previous approaches focus on race. To bring more balance to STEM with regards to gender, Ioanna Vekiri has explored the differences in the ways girls and boys come into contact with and are taught to interact with technology [20]. While Vekiri does not propose a concrete approach, the results of her study suggest some characteristics that an approach should have to be successful. The study was conducted with 7th grade students in Greece, with this particular time being chosen because 7th grade is when “information science is introduced in the curriculum as a separate subject" [20]. Because "females are more likely than males to value people- and society-oriented academic fields", activities "that highlighted the relevance of information science to everyday activities and professions" and made "connections between information science and other school subjects" would be more likely to engage more women in STEM fields [20]. Additionally, girls may benefit from working in same-gender groups because they "make more fair use of the mouse and try to resolve their disagreements with discussion, while in mixed-gender groups boys tend to be assertive and to dominate the mouse and the keyboard". Where the CSDTs and AADMLSS attempt to engage students using topics with which they are already familiar, an approach with these characteristics could be more easily fit into curricula. This type of approach can be used for any group of students as these methods do not only benefit girls. In fact, "boys were found to benefit equally with girls from practices that made content meaningful and relevant" [20].

Finally, we explore an approach that attempts to engage the student on the basis of environment instead of inborn characteristics like race and gender. Clarence Terry employed a counterstory approach to math with high school-aged students in Los Angeles [21]. This engages students by taking a look at their environment. Terry provides the following definition of a counterstory:

> I claim that a narrative constitutes a counterstory when it satisfies three key criteria: (a) contains a kernel or representation of the dominant narrative such that it communicates a clear understanding of that dominant narrative and its implications to the communicant; (b) provides the communicant (in the form of a competing narrative that is grounded in a 'freedom reality') reasonable and sufficient grounds for contradicting the dominant narrative; and (c) allows the communicant to access the larger freedom reality toward which the competing narrative pushes [21].

In his study, this translated to finding a potentially problematic argument and using math to disprove it. While not always giving the expected result, this approach provides motivation to use math instead of just presenting it "as a collection of facts and skills that are taught strictly as test content for testing's sake" in the form of a desire to root out misrepresentation of data [21]. Because it relies only on information from students' communities, this approach is not specific to any set of underrepresented students.

The approaches described above can be categorized using several of their characteristics. Eglash et al. define the "critical stance" in evaluating an approach [6]. This measure can take one of two values: social critique, in which students learn material through exploring real-world injustices, or social affirmation, where students find classroom connections through things over which they already feel ownership. We also explore how the approach combats stereotype threat. Stroessner and Good have identified several ways to actively combat stereotype threat, among them "reframing the task", "encouraging self-affirmation", and "providing role models" [17]. In choosing which of these methods was used most heavily, I found it difficult to decide between reframing the task and encouraging self-affirmation in some cases. I interpreted reframing the task as explicitly ensuring students that the results of a task would not reflect any aspect of their identity and encouraging self-affirmation as bringing to the forefront ideas with which the student was already familiar. In addition to counteracting stereotype threat, it is helpful to identify how students interface with or connect to the approach. In the case of these approaches, this connection can be made, as with the critical stance, through something over which the student feels ownership, on the basis of either race or gender. Where the critical stance is what the teacher is offering as a method of engaging the student, the interface is how the student actually engages with the material. Finally, we must consider the specificity of the method to know if we can extend it to students outside the target group. Approaches will be classified as either specific or generic. Table 3.1 summarizes these characteristics.

In trying to construct an ideal approach, we must find what these methods have in common. Three of these four approaches operate on a basis of social or self-affirmation. From these, it can be gathered that, as Vekiri states, students become more interested in STEM fields both in the classroom and as career paths when the material is shown to be useful in common activities and the workplace. For the sake of generality, it is preferable that neither a student's race or gender is emphasized in an effort to make the material seem more relevant to any one group. It is important to note that, as Terry points out, in many classrooms, "many of the intrinsic motivations that are assumed to be a part of schooling...fail to hold significance" [21]. Using counterstories as a teaching method may motivate students for whom this is true. Although only Terry's approach is presented here, there are many similar cases where math has been taught through social critique. After exploring these four approaches, it appears that instead of simply presenting the material as a set of concepts, the best way to reach underrepresented students is to highlight applications of the material.

Table 3.1: Categorization of Approaches to STEM

Approach	Critical Stance	Addressing Stereotype Threat	Interface	Specificity
CSDTs	Social Affirmation	Encouraging Self-Affirmation	Race	Specific
AADMLSS	Social Affirmation	Encouraging Self-Affirmation	Race	Generic*
Relevance	Social Affirmation	Reframing the Task	Gender	Generic
Counterstory	Social Critique	Reframing the Task	Environment	Generic

* This approach targets African-American students, but can be generalized to other student groups.

CHAPTER 4
THE DARWIN PROJECT

Darwin was not a supporter of racism or, by extension, slavery. His writings during his time on the Beagle suggest disgust at the treatment of the enslaved peoples he saw.

> Those who look tenderly at the slave owner, and with a cold heart at the slave, never seem to put themselves into the position of the latter; what a cheerless prospect, with not even a hope of change! picture to yourself the chance, ever hanging over you, of your wife and your little children - those objects which nature urges even the slave to call his own - being torn from you and sold like beasts to the first bidder! And these deeds are done and palliated by men, who profess to love their neighbours as themselves...It makes ones blood boil, yet heart tremble, to think that we Englishmen and our American descendants, with their boastful cry of liberty, have been and are so guilty... [23]

Unfortunately, because his ideas have been adopted and misused to these ends, people frequently assume Darwin himself was a racist. This misguided connection provided the motivation for the Darwin game.

The first portion of the Darwin game introduces the student to the people who influenced Darwin's attitudes prior to his voyage. His father makes an appearance and discourages him from going, but with his uncle's approval, he gets permission to set off. In addition to presenting some of his family members, we also introduce his taxidermy instructor. John Edmonstone, a freed slave from Guyana, learned taxidermy from his master's son-in-law [24]. After being brought to Edinburgh and freed, "Edmonstone settled in a house a few doors down from Darwin and his brother, Erasmus, earning his living stuffing birds at the Natural History Museum and teaching taxidermy to Edinburgh University students" [24]. The knowledge that Edmonstone provided allowed Darwin to preserve the finches he caught in the

Galapagos Islands. Once on board the Beagle, Darwin has an interaction with his captain, Robert Fitzroy. Fitzroy subscribed to the monogenist school of thought and "continually resisted Darwins growing doubts about special creation and the fixity of species" during their voyage [25]. The introduction closes with Darwin wondering how to disprove Fitzroy and support his family's ideals. The second part, shown previously in Figure 1.1, has the user deconstructing Fitzroy's ladder to build Darwin's tree. The most recently finished section has the student act as Darwin and catch several different types of finches. Once the birds are caught, the student has to match the bird's beak to the tool it most resembles. This game can be best categorized as an interactive based learning activity because students "act within the environment to accomplish their learning task" by using mouse activity to aid Darwin in completing tasks over the course of his voyage [16].

One flaw with taking a typical software development approach to building tools for potentially offensive subjects is making the assumption that all users will interpret the layout and content in the same way. During development, we encountered a problem with how to arrange the descendant pictures for the first stage. One of the reasons this arose during development instead of during design is that "comparatively little practical advice is available on how to understand culturally sensitive factors relevant to the design and development of learning objects" [16]. There are no resources for ensuring that a design handles sensitive material well. This is an issue because mishandling culturally sensitive topics could lead to a "rejection of the [learning tool]" [16]. In the case of a learning tool, rejection of the product potentially also means rejection of the material, which perpetuates underrepresentation.

The problem with the ordering of the images stems from the potential of students to interpret the ordering of the pictures as different stages of evolution, even when we are trying to convey a message in direct opposition to this. To better explain how we tried to solve this problem, I introduce two concepts. This thesis defines the word "mapping" as the type of spectrum that possible interpretations occupy. A mapping can be either discrete or continuous. I also introduce "cultural universality" as the property of having only one interpretation across all cultures and languages. We can examine the use of the word “primitive” as an example for how these terms will be used to explain our difficulties with the Darwin game.

“Primitive” can be used as a descriptor in multiple contexts. The two we will explore are relevant to cultures and software. Primitive, with regards to culture, has the connotation of less advanced. In software, it is used to describe basic or non-composite types. Segments of the underrepresented population have heritage ties to cultures that have been described as primitive, so it may be discouraging to see the word used in this manner in software. The use of the word “primitive” takes a discrete mapping - either the word is used or it is not, and this problem has a simple solution because there are alternate words with the same meaning. The connotation of “primitive” is culturally universal - every culture has the concepts of simple and more complex objects.

In the case of our images, we began with a display that had some vertical variation between the images. We wanted to model a tree, and trees do not have distinct levels of branches. Replicating this structure proved to be problematic because of the possible interpretations. Lakoff and Johnson call this an orientational metaphor - “high status is up; low status is down” [26]. This problem has a continuous mapping because there are an infinite number of configurations with vertical variation. Fortunately, this orientational metaphor is culturally universal, so this problem is easy to fix by just removing the vertical variation. However, this led to a new problem - possible interpretations of the horizontal layout.

The Darwin game is currently only available in English. English is read left-to-right, which means that the leftmost item is potentially seen as being in first place and the rightmost item in last. Having removed vertical variation, if we want to be able to see all the images at once, this problem has a discrete mapping with the number of options dependent on the number of images we are using. Because there are languages that read right-to-left, this is not a culturally universal issue. Solutions we have considered for this problem include using a random ordering for each user and avoiding gradients from fairer to darker (or darker to fairer) skin.

If we were to analyze the Darwin game in the same way as the above approaches, it would be a social critique, less of current times and more of Darwin’s time. It attempts to engage students on the basis of race. Unlike the approaches examined above that focus on race, this doesn't on any race in particular. In fact, out of necessity, it includes the overrepresented groups for the sake of showing equality. As a result of this, it can be classified as a generic approach.

CHAPTER 5
RESULTS

Because the Darwin game is still being built, it has not yet been tested in a classroom setting. However, to begin gauging the effectiveness of the completed portions, I took the software into a local afterschool program.

The school that hosted the program had halted afterschool programs between semesters, so attendance in the program I was working with was low, and as a result, I was only able to get two students to participate, both of whom regularly attended the program. The testing process consisted of having students take a pre-test and watch the introductory portion of the game. Students then completed the human tree portion of the game and filled out a post-test.

The pre-test consisted of two questions on a 5-point Likert scale. The first of these questions gauged students' understanding of how Darwin himself used his findings and the second asked students how the history of evolution affected their view of science as a topic of study. The post-test had 5 questions, three of them being unique to the post-test. Two of these three new questions used the Likert scale while the third was a short-answer question that asked students how their opinion of the theory of evolution had changed. The two Likert scale questions asked students how they felt lessons similar to the Darwin game would affect their interest in taking more science classes and their retention of science material.

Students did show a change of opinion between the pre- and post-tests. The first student I spoke with, an African-American male, thought that Darwin used his theories to claim that certain groups of people were less evolved than others. After viewing the introductory portion of the game, the student expressed surprise at learning that Darwin not only did not use his theories to this end, but instead did the opposite and attempted to use his theories to fight racism. The second student, an African-American female, expressed similar views.

While both students showed a difference in their interpretation of Darwin's use of his theory, neither student showed a change in thinking that the history of evolution did not change the appeal of science as a topic of study. It is important to note, however, that this may be due partially to students' lack of interest in science. One of the students had problems answering the post-test question about her change in opinion regarding the appeal of science because she said that she wasn't interested in science to begin with. Both students said that having lessons like this in other classes would help them with information retention and thought these lessons would either make them more interested in taking those science classes or, if they themselves were not interested in science, as was the case with one of the students, could make other students more interested in those classes.

CHAPTER 6
CONCLUSIONS

The Darwin game is still under construction, but it is already undergoing revisions. Some of the next steps under consideration aim to avoid having students watching long portions of animation without interacting with the software. To this end, we are currently thinking about how to make the introduction more interactive, with a potential avenue being having the student help Darwin collect some of the materials that he takes on his voyage.

During testing, in addition to getting an idea of how the software was changing students' views of Darwin and evolution, I was able to get feedback on the students' user experience with the game. The introductory portion did not seem to turn them away from the software because of a lack of participation, potentially because it is a relatively brief animation, but because some students learn better by doing and physically (or virtually, in this case) interacting with the material, making that part more interactive is still an area of interest. One feature of the human tree portion that we foresaw being a potential problem is the fact that there are no explicit instructions. Even though most students are experiencing this software having at least heard of evolution, they may have no idea of how to visually represent the theory. This represents one of the "limits to the active, discovery learning method", which is that "[i]f learners lack sufficient preparation they may become frustrated" [6]. While we do not want students to become frustrated, we also do not wish to give too much guidance because we feel that that would make playing the game trivial. Even if instructions are provided, students may apply their own interpretations to the instructions. In fact, during testing, one of the students attempted to connect the tree in the "opposite" direction, with the ladder segments pointing from the children to the common ancestor instead of from the ancestor to the children. The student understood the aim of the activity, but she approached it in a manner no one had previously considered.

In addition to improving the software, it is also important to better tailor the testing methods to the study. As one student noted, "there are more topics in science than evolution", so it appears that some of the questions I am asking students to consider are too vague.

The trends observed with the students in the afterschool program are consistent with the hypothesis proposed at the beginning of the thesis. It is our hope that as seen with these students, we can use lessons like these to improve performance in and engagement with STEM fields for underrepresented students.

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APPENDIX

The introductory phase of the Darwin game (named DarwinOpening) I used for testing is currently located here:

https://community.csdt.rpi.edu/projects/428/run

The human tree phase of the Darwin game (named DarwinLadder) is located here:

https://community.csdt.rpi.edu/projects/161/run

The finch phase of the Darwin game (named DarwinFinches) is located here:

https://community.csdt.rpi.edu/projects/177/run