Youth STEM Motivation:
Immersive Technologies to Engage and Empower Underrepresented Students

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There is no learning without engagement, a situation that happens all too often in our typically lecture-based classrooms. At the same time, engagement without learning, which frequently happens in today's digital worlds, is not a healthy alternative. Some claim that online gaming is one answer to engaging and motivating students in their academic work. Yet, students can frequently be engaged in these virtual worlds without actually learning anything or being more academically motivated.

In this white paper we describe a project underway at Harvard's Graduate School of Education in which we are designing innovative technological environments that draw from theories of motivation to support and augment the engagement and motivation of students in Grades 5-8 mathematics. First, we outline Bandura's (1986) social cognitive theory. Next, we describe facets of our project that utilize this theoretical framework. Finally, we describe areas for further research and pose questions with the hope that they stimulate productive discussion among the scientific and educational community.

Social Cognitive Theory

Social cognitive theory is rooted in a view of human agency in which individuals are agents proactively engaged in their own development and can make things happen by their actions. They are "partial architects of their own destinies" (Bandura, 1997, p. 8). Key to this sense of agency is the fact that, among other personal factors, individuals possess self-beliefs that enable them to exercise a measure of control over their thoughts, feelings, and actions, that "what people think, believe, and feel affects how they behave" (Bandura, 1986, p. 25). Bandura (1986) provided a view of human behavior in which the beliefs that people have about themselves are critical elements in the exercise of control and personal agency. Thus, individuals are viewed

both as products and as producers of their own environments and of their social systems. Because human lives are not lived in isolation, Bandura expanded the conception of human agency to include collective agency. People work together on shared beliefs about their capabilities and common aspirations to better their lives.

Rooted within Bandura's social cognitive perspective is the understanding that individuals are imbued with certain capabilities that define what it is to be human. Primary among these are the capabilities to symbolize, plan alternative strategies (forethought), learn through vicarious experience, self-regulate, and self-reflect. These capabilities provide human beings with the cognitive means by which they are influential in determining their own destiny.

<h2 style="text-align:center">Self-Efficacy Beliefs</h2>

Of all the thoughts that affect human functioning, and standing at the core of social cognitive theory, are *self-efficacy* beliefs, which can be defined as the judgments that individuals hold about their capabilities to learn or to perform courses of action at designated levels (Bandura, 1997). These self-beliefs touch virtually every aspect of people's lives—whether they think productively or self-debilitatingly; how well they motivate themselves and persevere in the face of adversities; their vulnerability to stress and depression; and the life choices they make. High self-efficacy also helps create feelings of serenity in approaching difficult tasks and activities. Conversely, people with low self-efficacy may believe that things are tougher than they really are, a belief that fosters anxiety, stress, depression, and a narrow vision of how best to solve a problem. As a consequence, self-efficacy beliefs powerfully influence the level of accomplishment that one ultimately achieves (see Pajares & Urdan, 2006 for a review).

How Self-Efficacy Beliefs Are Created

According to Bandura (1997), individuals form their self-efficacy beliefs by interpreting information primarily from four sources. The most influential source is the interpreted result of one's previous performance, or *mastery experience*. Individuals engage in tasks and activities, interpret the results of their actions, use the interpretations to develop beliefs about their capability to engage in subsequent tasks or activities, and act in concert with the beliefs created. Outcomes interpreted as successful raise self-efficacy; those interpreted as failures lower it.

In addition to interpreting the results of their actions, people form their self-efficacy beliefs through the *vicarious experience* of observing others perform tasks. Watching others solve challenging problems and overcome obstacles, for example, can help individuals to believe that they too can solve similar problems and overcome obstacles. Schunk and his colleagues have shown that *coping models*—those who struggle through problems until they reach a successful end—are more likely to boost the confidence of observers than are *mastery models*—those who respond to mistakes as though they never make them (e.g., Schunk, 1987; Schunk & Hanson, 1985, 1989). Coping models are especially effective for individuals who have difficulty learning, as competent people may perceive themselves as more similar to mastery models. For example, struggling math students who watch a peer model struggle through problems but who is eventually successful gain much more cognitively and motivationally than if they watch peer models effortlessly solve problems with no mistakes.

Social modeling is especially powerful when people observe a model whom they believe possesses similar capabilities as they do. Observing similar others succeed can raise observers' self-efficacy and motivate them to perform the task if they believe that they, too, will be successful. Hence, observing the successes of such models contributes to the observers' beliefs about their own capabilities ("If they can do it, so can I"). Conversely, watching models with

perceived similar capability fail can undermine the observers' beliefs about their own capability to succeed (Schunk, 1987).

Model similarity is most influential for those who are uncertain about their performance capabilities, such as those who lack task familiarity and information to use in judging self-efficacy or those who have experienced difficulties and hold doubts (Bandura, 1986; Schunk, 1987; Schunk & Meece, 2006). When people perceive the model's capability as highly divergent from their own, the influence of vicarious experience is greatly minimized. It bears noting that people seek out models who possess qualities they admire and capabilities to which they aspire.

Individuals also create and develop self-efficacy beliefs as a result of the *social persuasions* they receive from others. These persuasions can involve exposure to the verbal judgments that others provide. Persuaders play an important part in the development of an individual's self-beliefs. But social persuasions should not be confused with knee-jerk praise or empty inspirational homilies. Effective persuaders must cultivate people's beliefs in their capabilities, while at the same time ensuring that the envisioned success is attainable. And, just as positive persuasions may work to encourage and empower, negative persuasions can work to defeat and weaken self-efficacy beliefs. In fact, it is usually easier to weaken self-efficacy beliefs through negative appraisals than to strengthen such beliefs through positive encouragement.

Physiological and emotional states such as anxiety, stress, arousal, and mood states also provide information about efficacy beliefs. People can gauge their degree of confidence by the emotional state they experience as they contemplate an action. Strong emotional reactions to a task provide cues about the anticipated success or failure of the outcome. When individuals experience negative thoughts and fears about their capabilities, those affective reactions can

themselves lower self-efficacy perceptions and trigger additional stress and agitation that help ensure the inadequate performance they fear.

Overview of the Project:
Transforming the Engagement of Students in Learning Algebra (TESLA)

The overarching goal of this research project is to investigate the relationship between specific technology-based activities and students' motivation in math and interest in pursuing STEM careers along a developmental span. To facilitate this research, we are developing a four-day, classroom-based experience for students in Grades 5-8. After the administration of measures connected to our research, the first stage of this experience is a one-day induction activity, where the students will participate in one of three technology activities. In the second stage, during a two-day mathematics lesson, students will explore mathematical patterns. Students will spend the final day by participating in the technology activity again to conclude the experience. Students will then complete measures connected to our research immediately after and roughly six months after the experience. By varying the technological context of the induction and closing experience while holding the instructional component constant at each grade level, and by measuring motivation constructs before and after the experience, we can test a series of specific hypotheses relating outcomes of interest (such as value beliefs, competence beliefs, STEM career interest, and mathematics learning) to activity assignment within grade.

With the above overview in mind, the following research questions guide our project: What is the impact of the 4-day curriculum on students' math motivation, interest in pursuing STEM careers, and math achievement? To what extent is this impact influenced by factors such as the type of induction the students received and/or students' demographic and academic characteristics (e.g., gender, race/ethnicity, prior achievement)? And to what extent is this impact influenced by teacher-level factors such as teachers' mathematical knowledge for

teaching, credentialing in mathematics education, undergraduate major, years of experience, and teachers' beliefs (e.g., teaching self-efficacy)?

<div align="center">**Research Design**</div>

The Technology Inductions

The capacity of humans to think symbolically and to learn vicariously positions technologies like virtual environments as a potentially important tool to bolster the motivation of students in math (Chen, Dede, & Zap, *in press*). To do this we are designing three contrasting types of inductions to integrate with a 2-day mathematics curriculum unit, based on 1) student immersion in a virtual environment, 2) web-based, teen-friendly, interactive modules that teach a Growth mindset, and 3) educational videos. Figure 1 shows screenshots of each induction. We are contracting with a team of computer programmers to help design and develop the immersive virtual environments. By collaborating with them, our team of math educators and motivation researchers are able to weave the specific math content and motivational goals into the immersive environment. Because our goal is not to teach students the mathematics before they get to their math lessons, this environment has been designed to be exploratory by nature— students explore the world, try their hand at the mathematical patterns, and begin to form some initial conceptions about how mathematical patterns might work.

With regard to the second induction, we are working with researchers and developers of a web-based interactive module that teaches students about a Growth mindset—the harder you work, the more capable you become. These modules are based on the work of Carol Dweck and her associates, which have been shown to be quite successful at influencing students' motivation and achievement over a developmental trajectory (e.g., Blackwell, Trzesniewski, & Dweck, 2007).

Finally, with regard to the third induction, because we wanted to create an experience that would be legitimately used by teachers, and that might represent what a typical teacher might do to generate some interest in mathematics, we decided to use a PBS NOVA video that explores patterns. The video, entitled *Search for the Hidden Dimension*, explores the fascinating phenomenon of fractals and how they are used in everyday life such as building Smartphone antennas and generating visual effects in movies.

Because the bulk of our efforts have been spent in designing and developing the first induction, we focus our discussion on the virtual space environment. How were theories of motivation used in designing this induction? Recall that self-efficacy is built primarily from the four sources of self-efficacy. In tapping the first (and most powerful) source of self-efficacy—mastery experiences—commercial games already provide the scaffolding and "leveling up" designs that are helpful in building students' beliefs in their ability to succeed. Each of the four locked doors that students must pass through is a "leveling up" experience signaling to students that they have just finished a particular puzzle, and that they are now moving on to a more difficult one. As students attempt to figure out the patterns that arise in these puzzles, the environment provides mathematically appropriate scaffolds that help students, but only if they get stuck during the problem-solving process. Because this activity takes place during the first day of a 4-day intervention whereby students are exposed to the motivational activity on day 1 and then take part in an in-depth teacher-led mathematics lesson on the second and third days, this technology activity is designed to provide students with the belief that they can, in fact, succeed in learning to solve the mathematical patterns that they will face later in the intervention.

A potentially powerful and somewhat understudied aspect of the virtual environment we are designing and building taps students' vicarious experiences. We have created short video

interviews of real-life STEM professionals describing their experiences in learning math, and their subsequent path to a STEM career (see Figure 2). These young relatable professionals describe obstacles that they faced along their educational and professional paths and discuss the measures they took to overcome those challenges.

The message the professionals reinforce is that, with persistence and with the appropriate strategies, one can receive the training necessary to work in an exciting and rewarding career. The hope is that, because students are able to select from a number of young STEM professionals who are diverse in their occupations and outward physical characteristics (e.g., gender, race/ethnicity), students will be able to relate to one of these people and reap some motivational benefits. This design decision was made to address Bandura's contention that model similarity is an important component of what makes a model instructive. Because there is mixed empirical evidence about what constitutes model similarity, and because the literature on virtual models is scant, we hope our findings may help to illuminate which factors students consider when they select a STEM interview to watch.

As Bandura's (2001) and Sabido's (1981) work with telenovelas has shown, engaging television dramas can be created using vicarious models to instill large scale changes in human behavior. For example, soap operas were created to teach some communities about the value of furthering one's education, and provided viewers with information at the end of these shows to put them in contact with people and resources to help viewers achieve their educational goals. The popularity of such shows and the massive response of viewers in applying to educational institutions demonstrate the impact that interventions centered on vicarious modeling can have.

We believe that designers of technological environments can take a similar approach. Besides overt characteristics like gender and race/ethnicity, students may be looking for clues

about how similar the model is based on perceived relative ability (i.e., "is this person about as smart as I am?") and on attitudes (i.e., "did this person feel somewhat ambivalent about mathematics just like I do?"). For this reason, we asked each interviewee to dress fairly casually and to not say anything that might suggest that this person is not relatable to the average middle school student.

We also asked the professionals to talk about what they did not like about math and any other challenges they faced that may have stood in the way of them becoming a STEM professional. For example, one interviewee described the fact that he grew up "dirt poor and Black." Besides the material things that such a situation placed him in, there were also psychological consequences of this, such as thinking that "college is for those well-to-do kids who don't look like me." This particular person described how he had to overcome that thought, with the help of his father who pushed hard for him to go to college, before he seriously considered both a college education and more specifically a career in math and science.

Prospective Findings

Data from this study (which have yet to be collected) will help inform researchers and instructional designers about which types of technology activities tend to benefit which types of students the most. On the one hand, the virtual space world allows students to actively participate in the mathematics to be addressed in the math lessons, and allows students to take on the identity of a space explorer. It is designed to target self-efficacy as well as value beliefs. On the other hand, the Growth mindset modules are not specifically tailored to the math lessons; do not allow students to take on the identity of someone; and target students beliefs about math intelligence. By comparing students in each condition, we can explore which student-level and teacher-level characteristics tend to be associated more with motivational and/or achievement

gains in each condition. Moreover, because the third technology activity is a low-cost alternative that many educators are familiar with, and that has been used extensively in the past, we can explore whether the motivational and/or achievement gains of students were worth the cost to produce and deliver to a large number of students.

Future Directions and Questions for Discussion

We began this paper with the assumption that beliefs about competence are strong predictors of students' achievement in math and science and of their interest in pursuing STEM careers. However, beliefs about competence are not the only important motivation variables, nor are they always the strongest predictors. As Brophy (1999) has argued, there is a great need to study the value components of motivation as well. In fact, Brophy argued that, when it comes to motivation to do well in a particular subject or motivation to perform a specific task, competence beliefs might well be great predictors. However, when it comes to making larger decisions such as pursuing a STEM career, value beliefs may play a much more central role in students' motivation.

Therefore, steps should be taken to not only build adolescents' beliefs that they can succeed in math and science, but also to foster the sense that math and science are enjoyable (interest value), important to society (importance value), can help advance one's own educational, career, and personal agendas (utility value), and that the education and training are worth the time and effort (cost value). The question for researchers is how do we design and build technologies that can *meaningfully* and *authentically* foster these types of beliefs?

As Bandura (2001) and Sabido (1981) have shown, social cognitive theory can only provide the theoretical architecture on which actual products can be built. The next steps include the more micro level research involved in exploring the specific cultural milieus and

motivational belief systems that researchers hope to influence. For example, if researchers wanted to design and build technology activities targeted to rural poor students in the Southeastern US, there are cultural milieus that would no doubt greatly influence the types of vicarious models to use. These cultural milieus and belief systems are likely quite different from those of the urban poor in the Northeastern US.

Therefore, our basic assumption is that motivational activities are not a one-size-fits-all formulation. Rather, the technological activities that people design must be keenly attentive to the context of the targeted audience. These translational and social diffusion models, as Bandura has called them, are critical for motivation interventions to work. As a parallel, commercial video game designers are fairly attuned to their audiences when they design, build, and sell their products. For example, the FIFA soccer video games feature actual FIFA club teams and players with whom users can readily identify. Also, the cover of the video game changes depending on the country in which it is sold—in the United Kingdom, British players are featured, whereas in Italy, Italian players are featured.

As another example, any games, such as World of Warcraft, take the approach of including many motivational design decisions that are bound to be useful for someone. For example, World of Warcraft includes exploring a virtual world and seeing very visually stimulating landscapes, which may be motivational for some. Others may be motivated by the combat features of the game. Others may be motivated by buying and selling at auctions. And still others may be motivated by the social aspect of meeting, talking with, and going on adventures with either friends or other online users from around the world. In the context of educational settings, and more specifically, in the context of math and science motivation, how might designers and researchers decide on which route to take—the "kitchen sink" approach like

World of Warcraft, or the context sensitive approach similar to what Sabido and Bandura described for their television dramas?

Technology activities designed to motivate students in math and interest them in STEM careers may need to take similar approaches. The reason why, many times, such efforts do not take place is likely because of time and money. But can motivational inductions succeed with a broad audience unless sufficient time, effort, and money is spent to do so?

In addition to value beliefs, according to Ryan and Deci (2000), relationships are also important in motivation—students tend to be more motivated when they feel a sense of belongingness and connectedness in the activities in which they are involved.   As was evidenced by the television dramas created by Sabido, a key component of effecting change in people's behaviors and beliefs was providing contact information for viewers to receive more information about how to change their lives.

Innovative technologies possess considerable power in their ability to connect people around the world in an instant. Struggling students, especially those who are traditionally underrepresented in STEM fields, would likely benefit from feeling a sense of connectedness and belongingness. Social networking tools and immersive virtual environments are potentially useful tools that can aid in connecting disadvantaged students to vicarious models or organizations that can facilitate students' entry into STEM fields.

But how can these tools be effectively utilized in educational contexts? How are the relationships that are formed digitally different from the ones that are formed in person? And how might these differences be meaningfully addressed to motivate students in math and science and engage them in STEM fields? These are important questions for design-based research.

Finally, as mentioned earlier, students do not live their lives in isolation. Therefore, in addition to self-efficacy beliefs, *collective* efficacy may play an important part in motivating students in math and science. Again, this is especially likely with students who have been traditionally underrepresented in STEM fields. A recent example illustrating the power of collective efficacy is how youth revolts that began in Tunisia started an uprising across the Middle East. These revolutions were able to take place, to some extent, because of emerging technologies. How might technologies in educational contexts be designed to empower disadvantaged students to believe that they too can attain meaningful careers in math and science?

Conclusion

Technology cannot solve all of our problems in STEM motivation. As a tool, it is only as good as its creators' designs. As a teaching tool, immersive technologies still have a long way to go with regard to what constitutes "best design practices." As a *motivational* tool, they also have quite a long road ahead of them. Our hope is that this paper provides one piece of the puzzle to creating motivationally sound immersive technologies by outlining a useful theoretical framework on which to build. The real work now begins by exploring the translational and social diffusion models that can further the goal of motivating students in math and science, and boosting their interest in pursuing STEM careers.

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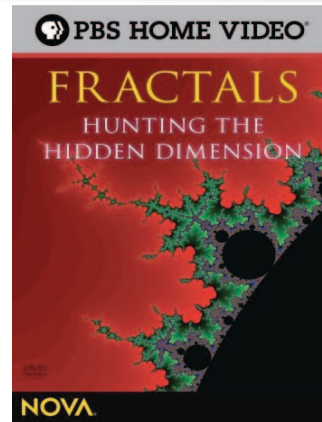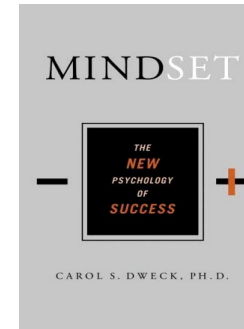Adolescents* (pp. 71-96). Greenwich, CT: Information Age Publishing.

Figure 1. Screenshots for Each

Induction 1: Virtual Space

Induction 2: Growth Mindset Web

Induction 3:

Figure 2. Interviews With STEM Professionals