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MOTIVATING STUDENTS' STEM LEARNING USING BIOGRAPHICAL INFORMATION

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Science instruction has focused on teaching students scientific content knowledge and problem-solving skills. However, even the best content instruction does not guarantee improved learning, as students' motivation ultimately determines whether or not they will take advantage of the content. The goal of our instruction is to address the "leaky STEM pipeline" problem and retain more students in STEM fields. We designed a struggle-oriented instruction that tells stories about how even the greatest scientists struggled and failed prior to their discoveries. We describe how we have gone about designing this instruction to increase students' motivation and better prepare them to interact and engage with content knowledge. We first discuss why we took this struggle-oriented approach to instruction by delineating the limitations of content-focused science instruction, especially from a motivational standpoint. Second, we detail how we designed and implemented this instruction in schools, outlining the factors that influenced our decisions under specific situational constraints. Finally, we discuss implications for future designers interested in utilizing this approach to instruction.

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CREATING STORIES ABOUT SCIENTISTS' STRUGGLES TO MOTIVATE STEM LEARNING

For decades, science instruction has focused almost exclusively on teaching content. For instance, typical science instruction teaches content, such as the structure of the atom or the DNA molecule, as well as the scientific methods or process that deduced protons and electrons and the data that generated the double helix model. The goal of science instruction that involves both the content and process is to help students engage in scientific activities similar to the work of a scientist in the field (Bell, Bricker, Tzou, Lee, and Van Horne, 2012; The Next Generation Science Standards [NGSS], 2013; National Research Council [NRC], 2000). The ultimate goal of our instruction is to address the "leaky STEM pipeline" problem and retain more students in STEM fields.

There is no doubt that content-driven instruction is important for students to learn. However, even the best content instruction does not guarantee that students will deeply engage with the material. Instead, students' motivation ultimately prepares them to better interact with content knowledge to improve their learning (Hong & Lin-Siegler, 2012; Lin-Siegler, Ahn, Chen, Fang, & Luna-Lucero, in press). It is especially important to consider students' motivation in science, technology, engineering, and mathematics (STEM) subjects because these subjects, in particular, are viewed as challenging where exceptional talent is required for success. In our recent interviews with high school students, all but one student reported that pursuing futures in STEM is unlikely because it is "too hard" or "only smart people do it." Holding such beliefs that high-level scientific performance requires exceptional inborn ability is de-motivating and undermines effort when it is most needed (Bandura, 1977, 1986, 1988;

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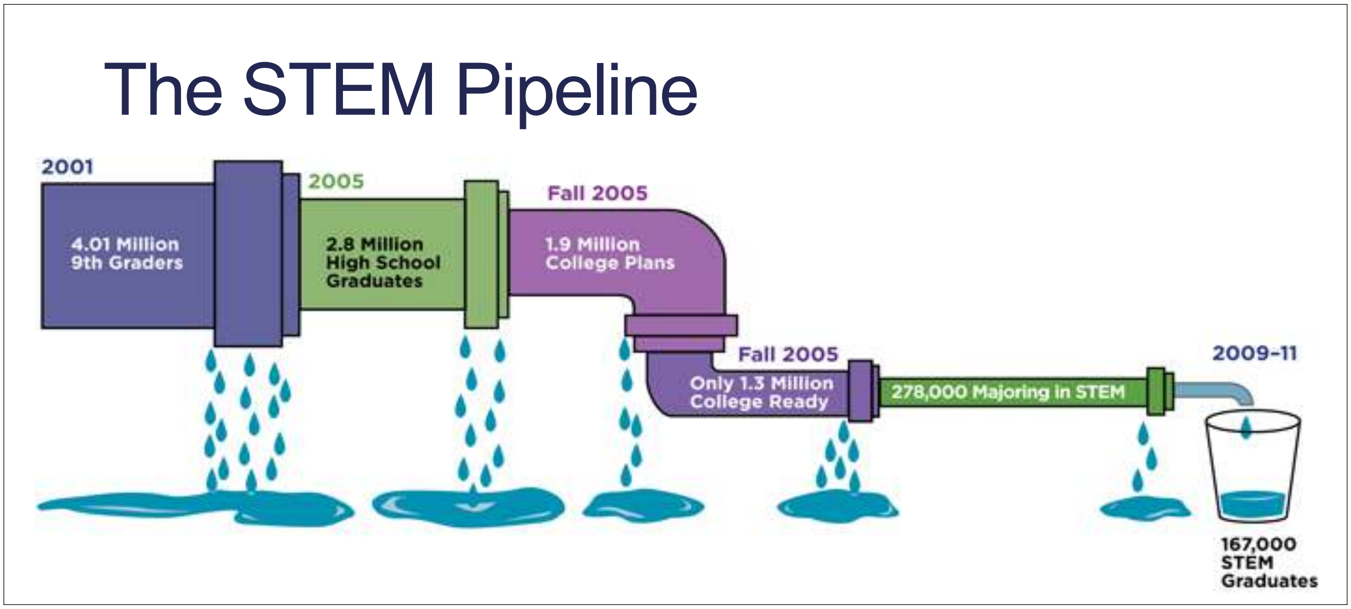

FIGURE 1. An illustration of the "leaking" STEM pipeline showing how more and more students do not end up pursuing STEM careers despite initial interest. Reprinted from Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics, Table C-6, The STEM pipeline [Online image], (2012). Retrieved from http://www.achieve.org. Copyright [2012] Washington, DC: President's Council of Advisors on Science and Technology. Reprinted with permission.

Dweck, 2000; Hong & Lin-Siegler, 2012; Murphy & Dweck, 2010; Pintrich, 2003; Rattan, Savani, Naidu & Dweck, 2012; Stipek & Gralinski, 1996). As illustrated in Figure 1, "The STEM Pipeline" is leaking, and it is not unreasonable to speculate that we are losing many potential STEM majors due to these de-motivating beliefs.

In this paper, we discuss how we have gone about designing a story-based instruction that presents scientists as ordinary people with limitations who struggled to achieve prior to their scientific discoveries. We provide information about how scientists' values, motives, personalities, and life experiences led them to sustain their effort through struggles. The goal was to challenge students' beliefs that unusually smart people created scientific knowledge.

This paper is organized into four sections. The first section describes the theoretical rationale for the approach we take to design our instruction. We designed our instruction to provide stories of how accomplished scientists (e.g., Albert Einstein, Marie Curie, and Michael Faraday) struggled and overcame challenges in their scientific endeavors. Our goal was to confront students' beliefs that scientific achievement reflects ability rather than effort. This struggle-oriented instructional approach is very much in the spirit of the self-determination aspect of motivation theory suggesting that basic psychological needs (e.g., needs for relatedness, competence, and autonomy) must be met in order to be motivated (Deci & Ryan, 1985; Ryan & Deci, 2000). The second section narrates how we applied a user-centered approach to design and implement this instruction in three iterations. The first iteration describes scientists' struggles generally. The second iteration describes a procedural and interactive approach to our instruction so that students can better apply the message (that success requires struggles) into their science learning. The third and last iteration describes a similar approach as the second iteration (procedural and interactive) and additionally allows students to directly experience the benefits of persisting through struggles. In the concluding section, we summarize our instruction with five design principles to support STEM learning for future designers.

Theoretical Rationale for a Struggle-Oriented Instructional Approach

Learning about science content knowledge and methods is important but can be a depersonalized approach to science (Eshach, 2009; Kubli, 1999; Solbes & Traver, 2003; for more on content-based instruction see Amos, & Boohan, 2002; Bennett, 2005; Sutman & Bruce, 1992). Depersonalized science is less attractive to students because it is often devoid of human endeavors, everyday contexts, and inflexible in study routines (Cawthorn & Rowell, 1978). This lack of "human" content in science teaching has several limitations.

According to self-determination theory, basic human psychological needs must be met in order to foster self-motivation so people can persist longer on tasks, apply more self-regulated learning strategies, exhibit higher intrinsic motivation, and perform better despite adversity (Deci & Ryan, 1985; Ryan & Deci, 2000). These needs are defined as needs for relatedness (Baumeister & Leary, 1995; Reis, 1994), competence (Harter, 1978; White, 1963), and autonomy (De

Charms, 1968; Deci, 1976). From a motivational standpoint, a depersonalized approach to science learning forestalls natural processes of self-motivation, which is essential to improve in science learning (and learning in general).

In the following section, we detail the limitations of a depersonalized approach to science learning and explain how providing scientists' struggles addressed these limitations by nurturing these basic human needs.

Limitations of Depersonalized Science Instruction

Stereotypes of scientists

Depersonalized instruction may lead students to develop stereotypical images of science and scientists. Students view scientists as unusually smart people who are divorced from reality, since they are disinclined to pursue mundane things, and instead prefer to pursue scientific wonders and esoteric knowledge that only a chosen few could comprehend (Chambers, 1983; Good, Rattan & Dweck, 2012; Mead & Metraux, 1957; Ward, 1977). As illustrated in Figure 2, when students believe that scientists are always smart people or geniuses who use little effort to solve scientific problems, they are more likely to perceive their failure as an indication of their lack of exceptional talent to do well in science (Dweck, 2010a, 2010b; Gladwell, 2008; Hong & Lin-Siegler, 2012).

Holding such stereotypical views of scientists perpetuates the disconnect that we observe between adolescent students and their understanding of scientists' work. Research has already shown that when people are viewed as very dissimilar from the self and common ground cannot be established, one tends to not associate with those dissimilar others (Tajfel & Turner, 1979). In fact, when relatedness to others is not felt, one distances from dissimilar others, even derogating and antagonizing them (Dovidio, 2001; Gaertner, Mann, Murrell, & Dovidio, 1989). Thus, depersonalized science instruction often fails to engage and motivate students in deep learning of the content.

In contrast, telling stories about how scientists struggled and even failed during their process of experimental work levers felt connectedness between students and scientists. Using this connection as a lever can lead to improvement in students' feelings of relatedness with the scientists, which in turn benefit their motivation to persist in their own studies and overcome hurdles when they occur (Hong & Lin-Siegler, 2012, Lin-Siegler et al., in press).

Lacking scientific procedural knowledge

Another limitation of depersonalized science instruction is that it conveys a static view of scientific discovery as an outcome, rather than a dynamic process where humans struggle to overcome obstacles prior to achieving their goals. Students in schools often work with declarative knowledge, or factual information about a specific domain. In order to apply the factual information, students need to learn procedural knowledge, or knowledge about how to do something. For instance, we can teach people the theory behind driving a car without actually showing them how to drive one. Such an approach does not guarantee that anyone will learn how to drive a car because truly knowing involves seeing and practicing. In parallel to science learning, depersonalized science underemphasizes procedural knowledge (Anderson, 1990, 2013, 2014).

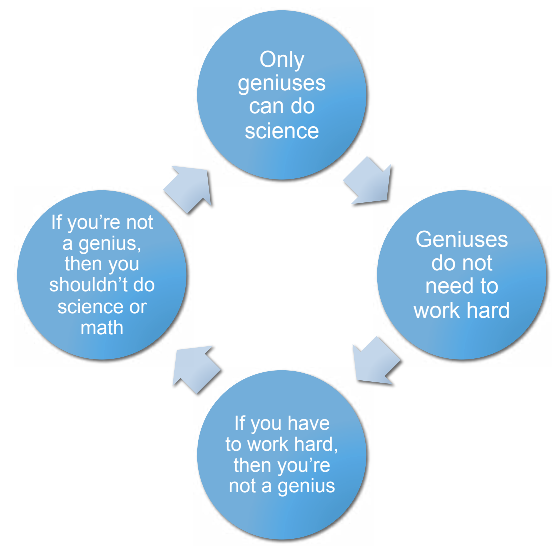

FIGURE 2. An illustration of the cycle of demotivating beliefs that steers students away from persisting in science learning. Reprinted from "Fear of failure prevents students to learn STEM," by X. Lin-Siegler, (2015). Paper presented at the meeting of the American Educational Research Association (AERA) Presidential Invited Address, Chicago, IL. Copyright [2015] by X. Lin-Siegler. Reprinted with permission.

When students believe that science does not involve an active and dynamic process, this belief bolsters the idea that they are not competent enough to skillfully master challenges in their environment (Deci & Ryan, 1985; Ryan & Deci, 2000), especially when students fail. That is, when students fail or encounter challenges in science and hold onto the belief that science does not involve a process of struggling, they might be prone to think that their struggling is indicative of their lack of competence. And, when an individual's competence is undermined, he/she is less likely to engage in actions in pursuit of the desired outcome, and even if he/she does, he/she will not invest 100% effort and persist (Dweck & Leggett, 1988; Oyserman, Bybee, & Terry, 2006). Learning about scientists' struggles makes explicit the process of scientific discovery, which counteracts students' beliefs that they are not competent because they have to work hard when solving problems.

Decreased interest in science

Depersonalized instruction may unintentionally hamper student's engagement and interest in science learning. According to Hidi and Anderson (1992), there are two kinds of interests—individual and situational interests. Individual interest is interest that students bring to the learning environment. Some students come to a science classroom already interested in the subject matter, whereas others do not (Mitchell, 1993). In contrast, situational interest is acquired by participating in the learning environment. For example, some learning environments are more motivating than others. Both types of interests enhance science learning, but individual interest usually develops slowly and tends to be long-lasting, whereas situational interest can develop quickly, but is often transitory (Hidi & Anderson, 1992).

Instructional designers tend to focus on stimulating situational interest by improving the appeal of textbooks or increasing the comprehensibility or readability of the texts (see, e.g., Graesser, León, & Otero, 2002; Otero, León, & Graesser, 2002) rather than enhancing individual interest. The lack of considering individual interest in instructional design undercuts students' sense of autonomy, which is the degree one feels that one's activities and goals are concordant with intrinsic interests and values (Deci & Ryan, 1985; Kasser & Ryan, 1996). For example, a student who lacks autonomy is assigned the chapter readings and does not take notes, participate in discussions, or ask questions. In contrast, a student who has autonomy sets a goal for himself/herself to read one chapter of a science textbook per night, actively takes notes, and asks questions when he/she does not understand the content. Presenting stories about scientists, their work, and their lives can inspire individual interest in science learning and enhance students' autonomy.

There are other ways that science content can be made more relevant. For example, emphasizing the benefits of scientific endeavor – better treatments for cancer, better screenings for early detection of cancer – can be highly motivating for students with family members impacted by cancer. However, emphasizing the benefits might not be sufficient in challenging students' beliefs about success in science. An important aspect of our struggle-oriented instruction is that it emphasizes the process of scientific discovery by normalizing struggle as a part of science (and learning in general). Doing so not only humanizes science content but also challenges students' beliefs that only unusually smart people succeed in science.

In summary, depersonalized instruction reduces students' interest and motivation to learn science because an exclusive focus on content knowledge undermines basic human psychological needs for relatedness, competence, and autonomy. When these needs are not fostered in the learning context, students are deterred from science learning. Exposure to scientists' struggles can aid science learning by fostering these innate needs.

For the remainder of the paper, we discuss how we designed our story-based instruction for schools, the factors that influenced our design, and how our instruction was implemented. Finally, we consider the implications our instruction has for instructional design and research.

THE EVOLUTION OF OUR STRUGGLE-ORIENTED INSTRUCTION

In general, the format of our instruction was as follows: During the first week, students received various pre-test measures that assessed their beliefs about intelligence (how malleable vs. fixed), stereotypes they held about science and scientists, and perceptions about their own ability to succeed in STEM areas. During the next 2-3 weeks, students read at least two stories about how famous scientists struggled prior to their discoveries (one story a week). In the final week, students filled out the same measures as they did during the pre-test to assess if there were any changes in their beliefs post-intervention.

A user-centered design and development approach required that our instruction meet three situational constraints: First, everything had to be comprehensible and understandable for our target population (8th-10th graders in urban schools). Second, the instruction had to fit into four (or five) 45-minute regular class periods (mainly during students' advisory classes). Teachers from all subjects (science, math, social studies, and English) led these advisory classes, which focused on lessons regarding academic and social/emotional issues and incorporating the messages of our instruction. Third, because not every student had access to a computer and most schools had unreliable Internet connections, our materials had to be text-based. Within these constraints, we designed our instruction.

The three main goals of our instruction were based on research on self-determination theory and intrinsic motivation (see Deci & Ryan, 2000). These goals were to: (a) improve students' felt and perceived relatedness to scientists, (b) confront students' beliefs about their competence and ability in science, and (c) increase students' sense of autonomy over their science learning. Our instruction attempted to foster these needs for relatedness, competence, and autonomy, so that students could better interact and engage with the content knowledge they learned in school. Therefore, it is important to note that our instruction was not designed for any particular science content knowledge. Instead, the goal was to enhance students' motivation so they are better prepared to learn the science content.

The way we implemented our instructional goals was guided by David McClelland's seminal work on achievement motivation. His work emphasized that teaching students how to think, talk, and behave as a motivated person would incite motivated actions (McClelland, 1969, 1972, 1987). A motivated person demonstrates actions such as vigorous enactment toward goal attainment, persistence in the face of obstacles, and resumption after disruption (Heckhausen, 1991; Lewin, 1926; Wicklund & Gollwitzer, 1982). Therefore, in the different iterations of our instruction, we progressively modeled for students how to stay motivated through challenges and persist through obstacles by detailing how scientists have similarly gone through struggles. Although we created several iterations of our instruction, we believe there are three main iterations that best capture our design principles (see Table 1 for an overview of these iterations; also see Appendix A for an example of the instruction that students received).

Iteration #1: Descriptive Instruction

The goal of the first iteration of our instruction was to present a general message of struggle (i.e., success in science requires effort more than ability) as a normal part of scientific achievement.

Content of the story

The instruction first began by introducing students to the scientists, providing basic biographical information about the scientist (e.g., birthplace, ethnicity, gender, etc.) and shifting to information about their research (e.g., "Marie Curie conducted experiments to help us understand radioactive energy"). Students also read about the struggles that the scientists encountered in the process of their scientific discoveries (e.g., multiple failed experiments). Then, they read motivational messages that exceptional talent is not required for success in science. For example: "How was Marie Curie so successful? Many think Curie was a genius who was born that way, but effort was needed to achieve her accomplishments. She realized that in order to succeed you have to try things over and over again even when you make mistakes or fail." Moreover, we focused on the key scientific discoveries that the scientists made and how those discoveries impacted the world: "Curie's determination resulted in changing both physics and chemistry."

Instructional approach

We presented general information about scientists' struggles to confront students' beliefs about succeeding in science. For example, Marie Curie's success was not a result of her exceptional ability, but of her hard work.

Implementation of the instruction

The first iteration was largely teacher-led instruction where the teachers instructed students to read the stories and answer questions about their perceptions. This means that the instruction was designed to reflect closely what students would typically experience in a classroom.

Iteration #2: Procedural and Interactive Instruction

A field-testing of this general struggle-oriented instruction points to a rather serious weakness. Students reported that the stories were interesting and engaging, yet, they had a difficult time understanding concretely why these

	MOTIVATIONAL GOAL	STORY CONTENT	INSTRUCTIONAL APPROACH
ITERATION 1	• Present information that scientists struggled.	• Present a general message about struggle. • Present biographical information.	• Story-based Instruction
ITERATION 2	• Explain scientists' goals. • Provide inspiring actions scientists took during the process of struggling.	• Emphasize the process of struggle. • Show the strategies used by scientists.	• Interactive Stories
ITERATION 3	• Highlight scientists' failures. • Have students experience the benefits of struggling and persisting.	• Highlight the specific types of failures scientists faced. • Show the specific strategies scientists used to overcome those failures. • Enable students to experience the benefit of persisting through a task.	• Interactive Stories, along with practicing persistence using supplementary activities.

TABLE 1. A conceptual summary of the three iterations of our instruction. This table depicts the three main iterations through which our instruction evolved. Included in this table are the goals behind each evolution, the story content, and the instructional approach employed.

scientists struggled and the specific strategies scientists used to overcome their struggles were not clear. For instance, students did not see any goals that the scientists were trying to accomplish or strategies they employed to reach those goals. If the goals for struggling are not made explicit and are not proceduralized, then students will have a difficult time modeling after the scientists' behaviors. This notion was addressed in the subsequent iterations of our instruction.

Accordingly, in the second iteration we: (a) proceduralized the process of struggling, (b) had the scientists model useable strategies, and (c) encouraged students to imagine themselves as struggling scientists.

Content of the story

Different from the first iteration, we prompted students in the second iteration to immerse themselves into the struggle stories by taking the perspective of the scientist: "Imagine yourself as a scientist." This was done so that they could mentally simulate the struggles that the scientists had to go through.

Additionally, the second iteration made explicit the process of scientific discovery and explained what motivated the scientists to persist and work hard. For example, "As a young scientist in France, [Marie Curie] observed a very strange phenomenon. If pitchblende, a dark and heavy mineral, was placed next to a piece of film, a dark image in the shape of the mineral would appear on the film." The story then vividly conveyed how Curie experimented with pitchblende. She experimented with others minerals, checked her calculations multiple times, and repeated her experiments over and over: "[Marie Curie] tried dozens of different combinations of rock, chemicals, and water to separate out the element that she believed was hidden inside the pitchblende." These examples emphasize how scientific experiments require an iterative process that takes persistence and effort.

Moreover, students received detailed descriptions of the hurdles and obstacles that the scientists (in this case Marie Curie) had to overcome: "Given that there was unfair sexism toward women scientists at that time, she had to convince her male colleagues to take her work seriously." Importantly, students even learned the strategies that the scientists used to overcome these challenges. They read that Curie met with 30 scientists individually and solicited feedback from them to improve her work: "In these meetings, she presented her work and then listened to each scientist's critique. With every meeting, she incorporated the new feedback she was given. As a result, she improved her presentation skills, learning to focus on the main points of her scientific research and the importance of her discoveries. Because of these efforts, she became widely respected in her field."

Instructional approach

We shifted from a more passive reading of the stories with a general message about struggle (first iteration), to a more interactive and action-inspiring instruction that modeled for students how to overcome struggle. First, the instruction was interactive and allowed students to openly discuss the experiences of scientists: "Describe the struggles and successes that Albert Einstein experienced in your own words."

Second, we introduced a "learning contract" so students could (a) set their own learning goals, and (b) develop strategies to reach those goals. The purpose of making their own contracts was to urge students to apply what they learned from our story-based instruction to improve learning in their own science classes. They were given the following prompts: "During the next week, I will improve my science classes by doing the following two activities: *(Be as specific as possible)*" and "The actions that I chose relate to the scientists' stories in this way." Students were encouraged to avoid writing general phrases like "try harder" and instead write specific actions. For example, they could consult a teacher, complete practice problems, and ask questions in class. In creating these contracts, students' sense of autonomy is enhanced because they are able to declare when and how they would take control of their science learning in the near future.

Implementation of the instruction

Whereas the first iteration of our instruction was what we described as "teacher-led" and "teacher-incorporated," the second iteration is what we describe as "student-initiated." We intentionally moved our instructional activities beyond solitary, self-paced reading towards active engagement, open dialogue, cross-talk in small groups, personalization, etc.). Additionally, we worked very closely and intimately with the teachers and principals of the schools to decide how to best deliver our instruction. Based on teacher and student suggestions, our instruction became part of an advisory class woven into a normal class day. Delivering our instruction in this manner made it easier for students to apply the messages and lessons learned into their own lives.

Iteration #3: Procedural, Interactive Instruction, Plus Experiencing Persistence

In the third iteration of our instruction, we tried more decisively to foster all three psychological needs (needs for relatedness, competence, and autonomy) by fulfilling these goals: proceduralize failures, model specific strategies, and (new in this iteration) give students the opportunity to experience the benefits of persistence. Exposing students to scientists' struggles in general (the first iteration) is not sufficient to truly enhance students' motivation, nor is it enough to emphasize the process of struggling to inspire action (second iteration). Students need the opportunity to *act out* their persistence and feel the resulting reward to incite motivated behaviors (see McClelland, 1969, 1972, 1987). In doing so, their sense of autonomy and competence are enhanced.

In addition, the first two iterations of the instruction emphasized how scientists struggled through their difficulties, while failures were less emphasized. Without vivid depictions of how scientists failed and how they overcame failure (i.e., responding to failure with specific strategies), it makes it difficult for students to model after the scientists' behaviors. Therefore, we proceduralized the process of failure more explicitly for students, as well as detailed specific strategies used by the scientists.

Particular to this iteration, we encountered contextual constraints. First, experiencing the benefits of persistence requires time, which we often do not have in schools. Second, selecting an appropriate task where students can persist in a meaningful way is also challenging because students vary in goal pursuits they deem to be desirable or feasible, and these factors typically affect how motivated a person will be (Bargh, Gollwitzer, & Oettingen, 2010; Gollwitzer & Oettingen, 2012; McClelland, 1978; Touré-Tillery & Fishbach, 2014). To best meet these constraints, we chose two tasks – reading a challenging science excerpt and working on a number combination task (detailed below in subsequent sections) – because these tasks met the practical challenges imposed on us, albeit not perfectly.

Content of the story

Unlike the previous iterations, the third iteration of the instruction began by having the experimenter share his/her struggle story. We hoped that beginning the instruction in this manner would increase the felt connectedness with the experimenter that would then transfer to the scientists.

The stories in this instruction pinpointed the *exact* failure that the scientists encountered and detailed the *specific* strategies they used to overcome the failure. For example, students read about how Marie Curie tried to disentangle the radioactive elements in pitchblende that would be most useful to her discovery. Students read the specific strategies and actions that Curie took to overcome this particular challenge: (a) she persisted, "After 1,000 experiments and an entire ton of pitchblende..."; (b) she stuck it out for a long time, "She didn't take any shortcuts or skip over any steps. Even a tiny miscalculation would ruin her experiment, so she made sure her measurements were accurate multiple times. She ran hundreds of experiments and kept a detailed record of what she did"; and (c) she sought feedback from others, "she met with nearly 30 important scientists one by one before the big meeting to receive feedback on her talk." Seeing the specific ways that scientists responded to the challenges provides students with a crystal clear template of how they could apply such strategies into their own lives.

Instructional approach

Similar to the second iteration of our instruction, the students engaged in various discussions with the experimenters regarding what they read and then created individual learning contracts.

The key element of the third iteration that was different from the others is that it gave students the opportunity to experience the benefit of persisting. They were asked to practice persistence in two activities (reading a challenging excerpt from a popular science magazine[1] and working on a number combination task). For example, in reading the challenging science article, students were told they could stop reading whenever they wanted. However, they were encouraged to read as much as they could. This task allows students to push themselves a little more and stick through challenges just a little longer. Students can see that the more they read, the more they can understand (similar to how Curie persisted in her experiments and eventually saw the benefit of staying on tasks longer).

Additionally, in the number combination task, students were shown the following numbers: 1, 2, 3, 4, and asked to arrange them in various combinations without repeating any order. This task was loosely based on Inhelder & Piaget's (1958) combinatorial reasoning task that examined whether young children are able to engage in scientific reasoning. In this task, students were able to develop a combinatorial system and draw further insights the longer they were able to stay with the task. Once students figured out a "system," they were able to complete the task.

Implementation of the instruction

Similar to the second iteration of the instruction, the third iteration was also "student-initiated." Students were given more opportunities to engage with the material through open dialogue and cross-talk in small groups.

CONCLUSION

Summary

In this paper, we discussed how content-based instruction primarily focuses on teaching students scientific content knowledge and skills. However, even the best content-based instruction does not guarantee improved learning, as students' motivation ultimately determines whether or not they take advantage of the instruction. We designed a struggle-oriented instruction to enhance students' motivation so they are better prepared to engage with content knowledge. Our instruction tells stories about how even great scientists struggled and failed prior to their scientific

1 The science excerpt was not related to any science content that the scientists in the stories engaged in (i.e., about radioactive materials that Curie worked on) nor was it related to any content that was currently being taught in students' science classes.

discoveries. We described how we have gone about designing our instruction and implementing it in schools, outlining the factors that influenced our decisions under situational constraints. With each evolution of the three iterations, our instruction progressively evolved to better foster the three psychological needs (needs for relatedness, competence, and autonomy) and modeled with precision how students could stay motivated.

Lessons Learned for the Project Team

There are important lessons we learned from designing our instruction. First, it is questionable whether the two supplemental activities used in the last iteration (i.e., reading through a challenging science excerpt and working on a number combination task) were ideal tasks to use. We are currently in the process of analyzing the data to assess whether these tasks were a good fit and continuing to brainstorm new alternative tasks to employ. As designers, we are constantly updating and revamping our instruction to better improve it in every way we can.

Additionally, based on preliminary data analysis, new questions have emerged such as whether having ethnic matches with the scientists might have a more potent intervention effect. Although we are in the early stages of analysis, we can only speculate that this might be the case, and we plan on doing further research to address this concern.

Finally, all the iterations of our instruction did not integrate science content. As stated, we kept content separate from our instruction because the goal was to enhance students' motivation to improve their own science learning. We acknowledge that researchers have demonstrated that integrating intervention methods and content materials enhanced students' performance and learning more than just providing the intervention alone (Bernacki, Nokes-Malach, Richey, & Belenky, 2014; Han & Black, 2011; Slavin, Madden, & Wasek, 1996). However, we wanted to create an instruction that was not tied too closely to any one type of science content. Instead, our goal was to create an instruction that could flexibly support any science content.

Design Principles of the Project Team

We have been working toward design principles in struggle-oriented instruction that are needed to affect students' motivation in science learning. There are many possible principles to which we could adhere, but we highlight the primary ones that we derived from the preceding discussion. They are:

1. Humanize content knowledge by providing the stories behind the product.
2. Reveal the inner and external struggles an individual (e.g., a scientist) went through.
3. Make the learning process vivid with explicit actions and strategies.
4. Portray the outcome benefits of struggling that are relevant to the individual's life.
5. Act out motivated actions and embody the model's actions.

Principle 1: Humanize content knowledge by providing the stories behind the product

Content-based instruction can be a depersonalized approach to science teaching. And, a depersonalized approach to science can lead to forming stereotypes about scientists (e.g., geniuses do not work hard), which can perpetuate the disconnect that we observe between students and their understanding of scientists' work. Infusing science content with personal biographies about how even famous scientists struggled and failed prior to their discoveries serves to bridge the gap between how students perceive scientists and scientists' work (see Lin & Bransford, 2010). Thus, we showed how great scientists (such as Albert Einstein) have failed prior to their achievements, thereby challenging students' beliefs that only unusually smart people succeed in science.

Principle 2: Reveal the inner and external struggles a scientist went through

Exposing scientists' vulnerabilities can increase the felt connectedness between students and the scientists. In our stories, we made clear both the personal and academic struggles that scientists experienced that made their journeys very difficult (e.g., both Albert Einstein and Marie Curie grew up in poverty and their families struggled financially). When students can visualize how scientists have gone through their struggles, this imagery challenges students' beliefs that only unusually smart people can succeed in science. When students' beliefs are confronted, their motivation to pursue STEM fields might increase because of the felt connectedness to the scientists, thereby enhancing their willingness to persist.

Principle 3: Make the learning process vivid with explicit actions and strategies

Confronting students' beliefs that exceptional ability is required to succeed in science might enhance their motivation to do better in their STEM classes, but this is not enough to motivate actions to pursue their goals. People have good intentions to pursue goals but often fail in executing the appropriate actions to fulfill these goals because of various external distractions (temptations) and internal self-regulatory failure (Gollwitzer, 1993, 1999). We may know *what* we need to do, but we fail in knowing *how* to do it (Gollwitzer, 1990, 1993, 1999; Gollwitzer & Oettingen, 2012).

In our instruction, we proceduralized struggles and failures by making explicit the types of problems the scientists encountered and the specific strategies they employed to overcome those problems. By doing so, students learn how to directly model after scientists' behavior when encountering similar struggles and failures in science learning.

Principle 4: Portray the outcome benefits of struggling that are relevant to the individual's life

Emphasizing the outcome benefits of struggling is important in keeping people motivated. If the outcomes are not clear, then students do not know *why* they should work hard and persist through difficulties (see literature on perceived short-term and long-term outcome benefits of activities; Ainslie, 1992; Loewenstein, 1996; Metcalfe & Mischel, 1999; Mischel, 1974; Mischel, Shoda, & Peake, 1988; Rachlin, 1995, 1996, 1997; Shoda, Mischel, & Peake, 1990; Trope & Fishbach, 2000). Thus, in our stories we mention the end goal for persisting. For example, Marie Curie worked hard to discover radioactive elements that ultimately led to her goal of helping people with illnesses: "After years of meticulous research and an entire ton of pitchblende, her hard work paid off when she managed to separate out not just one, but two new radioactive elements, which she named Radium and Polonium, after her home country of Poland. She reached her goal! Not only had she unlocked the mystery of pitchblende, she had discovered elements that could be used to create X-rays to diagnose illness."

Principle 5: Act out motivated actions and embody the model's actions

Finally, to further internalize the message that exceptional talent is not required to succeed in science, students were asked to *embody* the motivated behaviors they read about. Learning through complementary examples through which students can directly see, feel, experience, move, and manipulate (i.e., involve more senses) enriches the learning experience (Black, Segal, Vitale, & Fadjo, 2012; Chan, & Black, 2006; Han & Black, 2011).

In our last iteration, students had the opportunity to experience the benefits of persisting, but as acknowledged, the tasks used might not have been ideal (i.e., due to time constraints, design constraints, etc.). In the future, we will have students create a comic book in which they react to scenarios where they struggle and fail. By doing so, students could act out how they can remain motivated despite failure and apply the strategies they just learned from the scientists.

Currently, we are incorporating these principles to create an interactive multimedia-based instruction. As of now, our instruction has primarily relied on text-based format. However, people learn more easily when they are presented information in both verbal and visual form (Bransford, Brown, & Cocking, 1999; Cowen, 1984, Salomon, 1979). To better match the advancement of technology in students' lives and in our culture, we plan to deliver our instruction in movie form since "people can learn more deeply from words and pictures than from words alone" (Mayer, 2005, p. 1).

The ultimate goal of our instruction is to address the "leaky STEM pipeline" problem and retain more students in STEM fields. We will need more work to incorporate these design principles and to adjust our instruction accordingly. All in all, there are many ways we look forward to evolving our instruction and many directions we can go; we will continue to evolve our instruction so students, teachers, and designers can all benefit.

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APPENDIX A

Sample of our Struggle-Oriented Instruction

Today, we will read two stories together about the difficulties the world's greatest scientists experienced and how they overcame them.

Before beginning, please close your eyes and imagine that you are the scientist. What would you do and how would you feel in their shoes? You are now the scientist!

****

Even the Greatest Scientist Failed Before Succeeding

She grew up in Warsaw, Poland. When she was 10 years old, she lost her mother to a lung infection. There would have been a way to save her life if doctors had the proper materials. It was her mother's death that inspired her to study science. For her, learning science meant to understand how things work and how things happen in our lives. She decided to deal with the grief of losing her mother by throwing herself into her studies in order to help others like her mother in the future.

A Map of Europe in 1900s

Unfortunately, the Polish universities did not accept women at that time. She left home and traveled to Paris to study science there. To pay for her education, she took classes during the day and worked in grocery stores at night. She completed homework during her breaks. Her hard work paid off, she was one of the only two women who graduated with a degree in physical sciences.

****

Can you give us an example where you had a lot going on in your life while also trying to complete homework assignments and prepare for tests?

****

The effect of pitchblende on a photographic plate

As a young scientist in France, she observed a very strange phenomenon. If pitchblende—a heavy mineral—was placed next to a piece of film, a dark image in the shape of that mineral would appear on the film. It seemed like the mineral developed its own picture, even though there was no light in the room. She wondered if this material could be used in medicine—doctors were looking for a way to take pictures inside the human body. This material could have saved her mother's life.

She had a hypothesis that the unknown element contained in the mineral was radioactive. That meant the material was so powerful that it could release a huge amount of energy. But she had to run many experiments to prove that she was right.

Pitchblende: A Brown and Black Mineral

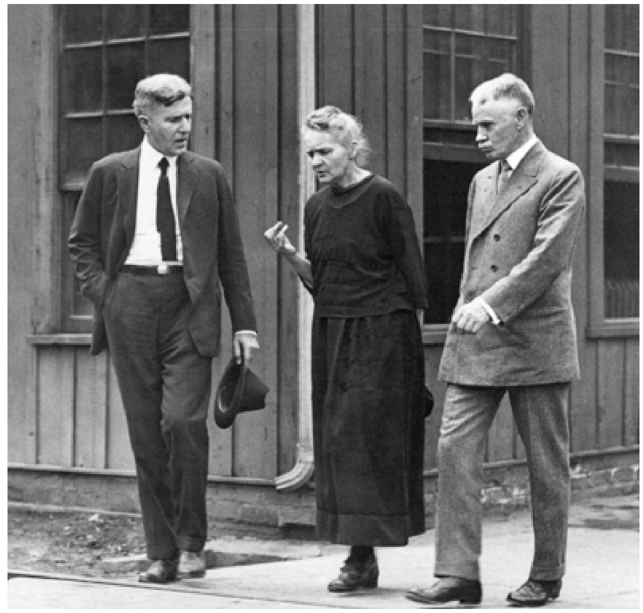
The pitchblende had many different materials inside of it and she had to discover the one element hidden in the mix that gives the radiation. She didn't take any shortcuts or skip over any steps. Even a tiny miscalculation would ruin her experiment so she made sure her measurements were accurate multiple times. She ran hundreds of experiments and kept a detailed record of what she did. But she knew the problem was too big to solve alone so she asked other scientists for feedback. Some thought that the elements she was searching for didn't exist, while others believed that she might find something very important.

Experiment 1	Experiment 2		Experiment end
Materials Used	Materials Used		
Procedure Followed	Procedure Followed	……	
Results	Results		
What went wrong and why?	What went wrong and why?		
Plans for next experiment	Plans for next experiment		

Checklist Used to Run Experiments

After 1,000 experiments and an entire ton of pitchblende, she managed to separate out not just one, but two new radioactive elements, which she named Radium and Polonium. She reached her goal! Not only had she unlocked the mystery of pitchblende, she discovered elements that could be used to create X-rays to diagnose illness.

She said, "The feeling of discouragement that came after so many failed experiments was upsetting, but the more I understood why I failed, the less upset I became. Each time I failed, I learned nothing in life is to be feared; it is only to be understood. Now is the time to understand more so that we may fear less." With each experiment, she learned something that made her next experiment work a little better.



Meeting With Other Scientists

****

Write about a situation where you did not do well in your classes at first, but you did not let yourself be beaten down. Instead, you studied more to understand and you improved in the end.

****

Marie Curie and Her Daughters

Scientific discoveries had to be shared in order to make a difference. Her next challenge was to present her work in a big meeting to convince other male scientists of her findings. Given that women scientists were not respected at that time, she knew that she needed to be proactive in order for them to take her work seriously. What did she do to be proactive? She met with nearly 30 important scientists one by one before the big meeting to receive feedback on her talk. After each private meeting, she made her points sharper and clearer.

At the day of the big talk, many male scientists walked in with doubts that her discovery was not anything useful. But as the talk progressed, they became more and more convinced that what she discovered was truly important to our lives. By the end of her talk, they couldn't help but feel excited about her discovery. They all stood up and gave her a loud applause.

****

Who do you think this story was about?

****

You may be surprised to know that this scientist is Marie Curie. Often, we talk about her success stories without mentioning the failure that she had experienced.

Later, when her daughters asked her about all these obstacles she faced, she said, "I have never been fortunate and will never count on luck, my highest principle is: **Predict what might go wrong and take extra effort to understand what you are doing**."

Marie Curie earned two Nobel Prizes (in chemistry and physics) and her work inspired the technology of X-ray pictures as well as advancing the ability to diagnosis and treat cancer and other illnesses. Her work truly helped to save lives, a dream she held since she was a child.

****

What images came to mind as you were reading the story?

****