The Role of Interest and Motivation in Science Investigation and Engineering Design Instruction

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Commissioned paper for the National Academies of Sciences, Engineering, and Medicine committee on Science Investigations and Engineering Design for Grades 6-12

10/25/2017

This paper was commissioned for the committee on Science Investigations and Engineering Design for Grades 6-12. The committee was convened by the Board on Science Education in Washington, DC with support from the Amgen Foundation and the Carnegie Corporation of New York. Opinions and statements included in the paper are solely those of the individual author, and are not necessarily adopted, endorsed, or verified as accurate by the Board on Science Education or the National Academy of Sciences, Engineering, and Medicine.

Abstract

In this commissioned paper, I synthesize findings from interest and motivation intervention studies to recommend guidelines for designing learning environments in 6th -12th grade science and engineering education. Part I of the paper describes promising results from motivation studies designed to target student intelligence beliefs and intrinsic motivations. In part II, I utilize an interest development perspective to suggest interest scaffolding as a way to increase interest, motivation, and learning during science investigations and engineering design work. I then describe some discussion of considerations for interest and motivation interventions for underrepresented groups in science and engineering in part III, and the role of intrinsic versus extrinsic motivators in part IV. Finally, I conclude with a call for more experimental research using intervention design studies to further our understanding of what interest and motivation supports work best for improved learning in science and engineering.

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The Role of Interest and Motivation in Science Investigation and Engineering Design Instruction

This paper is aimed at answering three central questions about the role of interest and motivation in designing science and engineering instruction for 6^{th} – 12^{th} grade students, particularly during investigation or design work. In the first three parts of this work, I address three main questions posed by the committee:

1) What information from the literature about interest and motivation is specific to the learning of science and/or engineering?
2) What are the implications of this information for the design and enactment of instruction where students do investigations or engineering design?
3) Is there any information about particular strategies that work differently for students from specific populations or backgrounds?

Each of the first two sections is summarized with a table listing recommendations for motivational interventions. In the fourth part of this work I will discuss the relationship between intrinsic and extrinsic motivation to address an additional concern raised by the committee. I conclude by summarizing findings from the four main parts, and making recommendations for future work. A glossary of terms is also included as an appendix.

To answer the first question posed by the committee, I will describe several social-psychological interventions from motivation literatures that have been found to be effective in science and engineering learning, and focus on 6^{th} -12^{th} populations if available. These are social-psychological interventions in that they are interventions made to address psychological issues or perspectives such as changing mindsets, adopting mastery goals, or improving personal value for learning in science. To answer the second question posed by the committee, I will utilize interest development research to provide design guideline recommendations for instruction involving science investigations or engineering design. To answer the third question posed by the committee, I will discuss recommendations for designing motivational instruction to address race and gender gaps in science and engineering learning. These interventions include presenting role models for these underrepresented groups, considering the relationship between multiple identities, and addressing external barriers to academic motivation and achievement. I then include a brief section describing current beliefs about the role of using extrinsic motivational approaches for learning in science and engineering.

It is important to begin by noting that motivation is a very wide area of research that includes theoretical perspectives that focus on Self-Efficacy (Bandura, 1986, 1997), Expectancy-Value (Wigfield & Eccles, 2000), Intrinsic/Extrinsic Motivation (Deci & Ryan, 1985; Malone & Lepper, 1987), Achievement Goals (Ames, 1992; Dweck & Leggett, 1988), Attribution Theory (Weiner, 1985), and Interest (Hidi & Renninger, 2006). This breadth of perspective in motivation may make the landscape difficult to navigate for non-experts and practitioners, but there is significant overlap among the theories. To focus the scope of this paper, I draw heavily on previous reviews from the following sources:

- Renninger, Nieswandt, & Hidi (2015): Interest in Mathematics and Science Learning
- Linnenbrink-Garcia & Patall (2016): Motivation
- Rosenzweigh & Wigfield (2016): STEM Motivation Interventions for Adolescents
- Lazowski & Hulleman (2016): Motivation Interventions in Education

In general, motivation has been found to be a key process or mechanism for enhancing student learning outcomes in science and engineering. (Lazowski & Hulleman, 2016). There is, however, no *direct* mechanism, but rather a series of interconnected and interdependent motivational constructs that have a collective effect on motivated behavior and subsequently achievement (Linnenbrink-Garcia & Patall, 2016). Research findings suggest that utilizing motivation to promote learning likely requires complex interventions to have high impact, but simple interventions have also proven effective (Rosenzweigh & Wigfield, 2016). The study of motivation on learning in STEM is heavy on theory that is informed by correlational or qualitative case studies. (Lazowski & Hulleman, 2016). Due to the nature of this commission, to make recommendations about the use of motivation to improve learning in science and engineering, I've chosen to focus on results from intervention studies rather than only theoretically prescribed guidelines. Using intervention research provides recommendations for interventions that have demonstrated effectiveness (Hulleman & Barron, 2016), intervention studies examining the role of interest and motivation in learning are somewhat rare, which limits the breadth and generalizability of these findings. For example: In a meta-analysis of motivation interventions in any academic content area, Lazowski & Hulleman (2016) found only 74 studies that met their criteria, but noted that most interventions had a moderate to high effect size with an overall effect size of $d = 0.49$.

Given the limited availability of intervention studies in any content area, intervention studies to explore how these constructs impact learning in STEM and specifically science and engineering are even rarer. One complicating aspect of the intervention studies that do exist is that many studies conduct research in one domain (e.g. math) and generalize their findings broadly to STEM. In their recent meta-analytic review of interventions in STEM education, Rosenzweigh & Wigfield (2016) found 53 studies that met their criteria. Of those, most involved motivation and learning in math, with several focused on science, and only a few that included engineering. One of the major limitations for inclusion of engineering intervention studies in their review is that most engineering education research aimed at studying motivation as a concept do not align with motivational theory or even present a clear definition of motivation (Brown, Mccord, Matusovich, & Kajfez, 2014). Another limitation in motivation intervention studies is that there is also a severe lack of studies that compare the effectiveness of interventions across different science and engineering disciplines. There is reason to believe differences exist, so further study into these specific motivational differences is needed – particularly in engineering fields, as there are only a few existing papers. In this paper, I will focus on intervention studies that closely align with at least one specific motivation theory, and that directly relate to learning in K-12 science or engineering. When possible, I will report effect sizes for each example, either directly from the authors, or post-hoc calculations from statistical reports[i]. Given the limitations, I feel that making recommendations that I believe are *specific* to science or engineering learning is not entirely possible. However, to compensate for the limited work in this area, I will also include some findings from other subject areas and college-aged studies that may also apply.

Part I: What information from the literature about interest and motivation is specific to the learning of science and/or engineering?

Unfortunately, interest and motivation in science and engineering education has not been given a thorough enough analysis to warrant claims about how motivational theories should be broadly applied specifically in these settings. I've discussed the lack of theoretically grounded intervention studies in these areas as one part of this problem. Another difficulty in prescribing motivational interventions, is that there is no unified model of inspiring motivation. Rather, there are several, often overlapping, theories, and many of these motivational constructs have reciprocal relationships with others (e.g. high interest can lead to mastery goals, but achieving mastery goals can lead to high interest; Harackiewicz, Durik, Barron, Linnenbrink-Garcia, & Tauer, 2008). To manage these difficulties, in this section, I attempt to synthesize the motivation literature, and organize potentially effective interventions into two categories of interventions: those that target student intelligence beliefs, and those that target student intrinsic motivations.

Intelligence beliefs, in this paper, concern interventions that target a student's belief that they can accomplish a task. These interventions include attributions, mindsets, expectancy and self-efficacy interventions. The second category, intrinsic motivations, is not strictly in line with the traditional model of intrinsic/extrinsic motivations (Deci & Ryan, 1985). Intrinsic Motivations, in this paper, concerns interventions targeted at increasing a student's internal desire to learn and achieve. These interventions include personal and utility value, achievement goals, and individual interest. Both intelligence beliefs and intrinsic motivation interventions target student perceptions, specific to science and engineering, that can be barriers to motivation. In general, some students feel/perceive/have: Firm beliefs that they "just can't do" science or engineering; stereotypes that exclude groups from feeling they *can* participate; little experience with science or engineering outside of academic context; and/or a perception that learning in science or engineering has little inherent value to them (e.g. "When will I ever use this?") These barriers can be overcome through social-psychological interventions that target specific or multiple motivational constructs. While increasing motivation through interventions is often associated with increases in learning, this is not always the case. Thus, I will also attempt to focus on interventions that have been associated with both increases in the targeted motivational construct and enhanced learning outcomes in science and engineering.

Interventions for influencing intelligence beliefs. I will begin this section by first presenting potentially successful interventions that are associated with targeting attribution and mindsets and then those that are associated with self-efficacy. In the first type of interventions, attribution and mindset training, students are given lessons on their capacity to increase their knowledge and/or their belief that effort and ability to improve determine success. Students become armed with knowledge about their ability to improve in science and engineering, and this can help to remove the "just can't do it" barrier to achievement. Correlational studies in this area have demonstrated that a growth mindset and attributing internal effort to success are related to higher academic achievement (Blackwell, Trzesniewski & Dweck, 2007). Recommendations for interventions from these fields include methods of providing students with informational supplements to promote a growth mindset and/or lessons that emphasize or demonstrate how effort and ability to improve will lead to success (e.g. Boese et al, 2013). These supplements can occur as lessons before or during normal class activity, or through teachers being trained to focus on praising student challenge, effort, and mistakes during learning as valuable to their achievement and learning (Dweck, 2008). For example, Ziegler and Heller (2000) used attribution retraining that corresponded with improvements in 8th grade physics achievement for high achieving girls. In this study, teachers were trained to give feedback on student work that emphasized that the student's effort was responsible for their success. After one year of the physics classroom intervention, students in a treatment group demonstrated increases in their belief of an internal attribution of success (i. e. believing that success is attributed to effort) and achievement test scores as compared to a control group (d = 0.31). Similar outcomes were found for high achieving high school girls (although importantly, not for boys, who had begun the study with significantly higher beliefs in internal attributions of success) in chemistry who received attribution training through informational videos (Ziegler & Stoeger, 2005; d = 0.38), and for students with low internal attribution of success in high school math who received teacher feedback promoting attributional beliefs (Sukariyah & Assaad, 2014; d = 2.58). In a large-scale study using mindsets training, Paunesku et al. (2015) demonstrated a positive impact on grades in math, science, and English for students at risk of dropping out who received growth mindset training (d = 0.21). The training involved reading an article about the brain's ability for growth and that academic difficulties are opportunities to learn rather than an indication of limited potential. A related approach to illustrate how difficulties are an opportunity for growth rather than a demonstration of limited potential is by teaching students about how famous physicists struggled to achieve scientific progress. This intervention improved learning (recall problems, d = 0.61; complex problems, d = 0.89) and interest (d = 0.67) in science for high school students when compared to students given materials focusing on great achievements by physicists (Hong, & Lin-Siegler, 2012). Overall, teaching middle and high school students about the value of difficulty and their natural capacity for improving in science and engineering appears to be an effective method of improving motivation and achievement in these fields.

Similarly, interventions that target increasing student self-efficacy have also demonstrated a positive effect on motivation and achievement in science and engineering. Increased self-efficacy is associated with greater effort and self-regulatory strategies that can have a positive effect on academic achievement (Linninbrink-Garcia & Patall, 2016; Bong, Lee & Woo, 2015) and is highly correlated with interest in math and science (Bong, Lee, & Woo, 2015). In this type of intervention, a student's self-concept of their ability is influenced through four types of experience: mastery experiences, vicarious experiences, verbal/social persuasion, and emotional states (Bandura, 1997; Schunk, 1990). Promoting students experiencing achievement (i.e. mastery experiences) appears to be the most common approach to positively influencing self-efficacy. One approach to improving mastery experience is to have instructors set appropriately challenging material for individual students, or allow students to set their own goals. This method gives students meaningful, but achievable goals that invoke a sense of accomplishment is the student. Fencl & Scheel (2005) also found correlations between several teaching strategies and self-efficacy. They found that assigning conceptual problems, or have students engage in inquiry labs, collaborative groups, and question and answer sessions all were associated with improved self-efficacy. These types of learning environments may provide opportunities for engagement that students may find conducive to experiencing social persuasion of their ability and experiences of mastery of the material. While most work seem to focus on mastery experiences, Chen & Usher (2013) recommend attempting to include multiple paths to increasing self-efficacy (i.e. mastery and vicarious experiences) rather than simply mastery experience interventions. While this method of intervention does seem promising, there appear to be very few intervention studies aimed specifically at increasing self-efficacy in middle and high-school science or engineering. Examples of a mastery experience intervention from college level inquiries are a series of studies using worked examples and self-explanations during learning that improved learning (d = 0.69) in chemistry (Crippen & Earl, 2004) and learning (d = 0.10) and self-efficacy (d = 0.41) in physics (Crippen & Earl, 2007). In these studies, the authors created a web-based learning system that tailored content to the student's ability level, provided worked examples, and included a means for students to self-explain their problem-solving approach. When students are given both worked examples and opportunities for self-reflection, there was a significant impact on student exam scores, final grades, and self-efficacy. Similar results were found by Sung and Hwang (2013) with elementary students in science learning. When students learned in an educational science game with both collaborative and mastery supports there were increases in both test scores (d = 1.06) and self-efficacy (d = 1.07) for science. While there is strong correlational evidence for the relationship between self-efficacy and learning, the availability of 6^{th} -12^{th} grade science and engineering studies is limited. What evidence we do have is promising, but further investigation is certainly needed.

The interventions described thus far target student beliefs about their ability to be successful in science and engineering learning. While these interventions have proven to positively impact learning, they do not specifically address the learner's desire to engage and succeed that may be needed to sustain long term engagement. To impact students' internal desire to learning in science and engineering, some researchers employ methods of targeting student intrinsic motivation.

Interventions targeting intrinsic motivation. A major approach to interventions aimed at improving intrinsic motivation are to attempt to increase a student's sense of value or connection to science and engineering. The most prevalent way of doing this is through interventions that seek to increase student value for the content being learned, but improving student's perception of what real science and engineering jobs are like has also been effective. During value interventions, researchers seek to improve a student's perception of the usefulness of the work they are engaged in, and have been effective in demonstrating increases in interest, motivation, and learning in science and engineering settings. Targeting value for academic content is an intervention that spans several motivational theories that include: achievement goals, expectancy-value, intrinsic motivation, and interest[ii].

In general, across motivational theories, value interventions are thought to be successful, because the intervention allows students to see a direct connection between what they value and the content they are learning. This connection can be self-generated, or done through direct and indirect messages. Some findings indicate that self-generated value interventions appear to benefit low-ability/low-self-concept learners, and directly describing the value of the content to the learner appears to benefit high ability/high-self-concept learners (Durik, Hulleman, Harackiewicz, 2015). For example, Hulleman, & Harackiewicz (2009) found that when low success expectancy students self-describe the personal relevance of the learning tasks it improves interest and grades in high-school science (effect size not available). In this study, the authors had high-school students complete writing prompts that asked them to describe how the work they were doing in biology and physics related to their lives. Another self-generated value intervention was done by Miyake et al. (2010) who found that writing about personally important values improved grades for college women in physics (but not men; $d = 0.25$). Intervention research of these indirect value interventions is fortunately more widely available than student intelligence belief studies, but they are still limited and require further research.

Direct value interventions have also been found be impactful. Harackiewicz, Rozek, Hulleman, and Hyde (2012) used brochure mailings and a web site to support parent belief in the usefulness of taking high school science courses and to guide parents in talking to their children about the utility of math and science. Students in this intervention demonstrated increased enrollment in high-school science courses ($d = 0.33$) and increases in utility value of science courses if their mother's perception of utility value also increased ($d = 0.32$). Later, a follow up study found that these same students had higher math and science ACT scores ($d = 0.33$), and greater pursuit of STEM careers ($d = 0.33$; Rozek, Svobodab, Harackiewiczc, Hulleman, & Hyde, 2017). Similar findings from Acee and Weinstein (2010) also provide evidence that providing messages about the value of learning the content, in this case statistics, led to improved task value ($d = 0.54$) and grades for students with one of the instructors ($d = 1.58$) for college students.

Another approach to impacting student intrinsic motivation in science and engineering uses personal relevance interventions to improve student interest and learning in science and engineering. One method of increasing personal relevance is by exposing students to concrete examples of the variety of work that real scientists and engineers do. This type of intervention challenges some of the stereotypical images of professionals in these fields, and students may then have a more concrete and complex picture of science work to relate to. Wyss, Heulskamp, and Siebert (2012) used this type of intervention in STEM learning by having students view video interviews with scientists about their careers, and found a positive influence on increasing interest in pursuing STEM careers for middle school children (*d* = 0.52), but no learning gains were measured. Another approach is through place-based learning (Sobel, 2005). This method, often used in environmental education, focuses science and engineering investigations on problems and phenomena that exist in the local community. Students are more likely to make personal connections, and see science and engineering as more relevant to their lives by working on problems they can directly identify with. Using placed-based learning can be especially powerful when it is student driven, that is the students identify the problems (e. g. poor drinking water quality) or phenomena (e.g. a local aquifer) to investigate. Place-based learning has had a positive influence on learning and motivation when collaborating with the surrounding community on environmental issues such as local air quality (Powers, 2004; Senechal, 2007; effect sizes not available).

Overall, it is believed that increasing a student's personal value and connection to science is an important method of promoting intrinsic motivation for studying and learning in science and engineering. Intervention studies in this area have shown promising results, but have mostly been done through personal value studies, suggesting that more research on other methods of increasing connections to science and engineering is warranted
Table 1

Summary of Motivation Interventions for Increasing Learning in Science and Engineering

	Intervention Type	Effect size (*d*)	Intervention Methods
Influencing intelligence beliefs	Attribution Training	0.31 to 0.38	Students engage in lessons (e.g. videos or articles) before or during learning activity that emphasize that effort rather than innate ability determine success in science and engineering.
		2.58	Feedback from teachers praises effort, and describes challenge and mistakes as opportunities to learn.
	Mindset Training	0.21 to 0.89	Students engage in lessons (e.g. videos or articles) before or during learning activity that teach children their brain is malleable, and be trained to improve ability in science and engineering.
		N/A	Feedback from teachers demonstrates how success is related to increased student ability, and how anyone can improve with practice.
	Increasing Self-Efficacy	0.1 to 1.06	Individual students engage in learning activities that allow them to demonstrate mastery through meaningful but attainable goals.

		N/A	Teachers assign conceptual problems, or have students engage in inquiry investigations, collaborative groups, and question and answer sessions
Increasing intrinsic motivation	Value Interventions	0.33 to 1.58	Teachers, school administrators and researchers directly relate the value of learning science and engineering to parents and high-motivation students.
		0.25	Low-motivation students self-generate a description of the value of learning science and engineering.
		0.52	Lessons and learning experiences represent a broad range of real science and engineering practitioners and their activity.
		N/A	Lessons and experiences include problems and phenomena tied to the students' local community.

Conclusion to Part I. The interventions described here have been selected primarily for their potential impact on improving student motivation and achievement in science and engineering content. These results indicate these interventions can effectively change student motivational variables, and subsequently impact achievement. However, research in this area, particularly for science and engineering education, is severely understudied and requires more deliberate research that seeks to find ways of directly influencing student motivation to improving student learning. This problem becomes even more acute in light of the need to better understand how to design interventions that are particularly tailored to meet the needs of students in science and engineering learning environments. Table 1 summarizes the recommendations from each intervention.

Part II: What are the implications of this information for the design and enactment of instruction where students do investigations or engineering design?

The quality of learning during science investigations or engineering design work is dependent, in part, on the student's interest and motivation to engage during the activity (Blumenfeld, Rogat, & Krajcik, 2006). In turn, the quality of their engagement is related to the student's individual dispositions towards science and engineering that includes their interest, identity, academic goals, expectancies, values, and a host of other complex psychological constructs (Hidi & Renninger, 2006). Of these theoretical positions, I believe that interest development is best suited as a theoretical model for informing the design of science investigation and engineering design learning environments, because it focuses on both in-the-moment, situational engagement and developing a long-term pre-disposition to re-engage with an activity, and this theoretical perspective has significant overlap with many other motivational theories. Therefore, in this section, I will focus on recommendations derived from interest development research. As with other motivational theories, interest development intervention studies are limited, and intervention studies done in the context of science investigations or engineering design work are rare (Krapp & Prenzel, 2011). Thus, Part II will provide design guidelines that represent promising practices rather than well tested methods of intervention.

Research in interest development has developed several prescriptive methods of maintaining and increasing interest that can be used as lesson design factors to promote quality and sustained engagement in science and engineering activity, particularly for the relatively long-term projects and activity that science investigation and engineering design work entails (Renninger, Nieswandt, & Hidi, 2015). There are two important considerations that I will focus on in reporting these lesson design recommendations: the need for scaffolding, and the importance of socially situated learning. First, there are crucial differences in the interest development needs of highly and less motivated learners (i.e. high and low individual interest[iii]) in science and engineering to optimally increase or sustain their interest (Hidi & Renninger, 2006). Low interest learners often require much more external support to sustain engagement in a task, and this level of interest is often referred to as *situational interest*. In contrast, high interest learners have developed an *individual interest* for the subject of the task that compels them to seek engagement with the subject, and to persevere through difficulty on their own. These differences require lesson designs to be appropriately scaffolded to meet the differing needs of high and low interest students (Järvelä, & Renninger, 2014), and the scaffolds need to be gradually faded and modified over time to appropriately adapt to changes in the student's interest and abilities (Puntambekar & Hübscher, 2005). Therefore, proper calibration of interest scaffolds requires a continual estimates of student interest and ability in the domain. A second important consideration is the growing movement to increase the implementation of situated and social-cultural approaches to research interventions utilizing interest and motivation that warrant greater consideration by practitioners. (Azevedo, 2013; Pressick-Kilbourn & Walker, 2002; Bobbit-Nolen & Ward, 2008). Therefore, I will provide recommendations that include specifications for low and high interest students, and emphasize socially situated learning activity. Unfortunately, there is a severe lack of studies specifically targeting specific interest development factors in science investigations or engineering design, and the examples for each design factor are from other content areas and other activities. There are some studies available that take a more holistic approach to developing interest, and I conclude Part II with a series of these as examples that demonstrate the inclusion of several of the design guidelines discussed here.

Design factors and guidelines from interest development research. Several major design factors can be taken from interest development theory to promote interest, engagement, and learning that should be considered when designing learning activities. These factors include: providing choice or autonomy in learning, promoting personal relevance, presenting appropriately challenging material; and learning within activities that are appropriately socially and culturally situated. First, the design of lessons to support choice and autonomy is important to interest development and learning. When students are engaged in science investigations or engineering design work, there are instructional design decisions to be made regarding how structured and rigid the flow of the activity is. Research on interest development suggests that allowing students some flexibility to choose the direction or content of their learning (Deci &

Ryan, 1985 ; Patall, Cooper, & Wynn, 2010), particularly in science and engineering (Nieswandt & Horowitz, 2015), and having options that relate to one's other interests (Azevedo, 2013; Walkington, 2013) can benefit interest development and learning. Too much choice, particularly with lack of knowledge about those choices, can have negative consequence that can lead to random choice or being overwhelmed by the choices (Katz & Assor, 2007; Bereby-Meyer, Assor, & Katz, 2004). To implement choice supports for interest development, the following design recommendations may be beneficial in creating learning activities. For low-interest students provide few, relatively simple choices, and choices that connect to a variety of other possible student interests outside of the content being learned. For high interest students, provide complex choices or open-ended options for pursuing the learning activity that allow the student to explore aspects of the content in more depth. For example, Patall (2013) found that students who could choose from several articles to read outperformed those who could not choose on reading comprehension (d = 0.31), and were more motivated to read materials that were perceived as boring (d = 0.64).

The second set of design guidelines for creating learning activities in science investigations and engineering design are focused on the relevance of the work to the student. Tailoring science investigations and engineering design work to be perceived as relevant to the student is important for engagement and learning (Järvelä, & Renninger, 2014), and is often done through value interventions as described in the previous section. While the previous section enumerates several studies that demonstrate effective interventions in this area, I will provide additional design recommendations for scaffolding these interventions here. For low-interest students, it can be beneficial to allow learners to self-generate their estimation of the value for the work as part of the learning activity or prior to beginning their work. However, very low-interest learners may need some support for self-generating value, since they may have such little experience with the content, that they struggle to make any connections (Brophy, 2008) One effective means of doing so is providing suggestions from peers as examples of making value connections (Gaspard et al., 2015). High-interest students can benefit from directly demonstrating the value of the content to the student or for experts in the field. Finally, both low and high interest learners can benefit from activities or problems that incorporate broad examples of real science and engineering practitioners and the type of work that is done in their specific disciplines.

The third set of design principles are based on creating lessons and activities that are appropriately challenging for the student. Optimal difficulty and complexity of a task influences situational interest in that task and can impact long-term individual interest development (Nieswandt & Horowitz, 2015). While high interest students thrive in challenging environments (Renninger & Su, 2012), low interest students may lack the self-regulation and perseverance that is required to engage with work that is too difficult for them (Sansone, Thoman, & Fraughton, 2015). For example, Fulmer and Frijters (2011) had students read passages that specifically tailored to be difficult for them to read, and that those who reported a higher interest in the reading task were more likely to continue reading (d = 1.33). Design recommendations for optimal task difficulty for low-interest students suggest that activities should be at least somewhat novel and have moderately challenging problems, include short procedural directions for next steps, and provide feedback that conveys appreciation for the difficulty of problem for the child. Those students with an existing high-interest in science or engineering can benefit from an increase in novelty and from problems that are more challenging for the learner. High interest learners also appear to be benefit from abstract or conceptual hints and feedback, and require less frequent appreciation for their work. These design principles all provide content for the learner that allows them to meaningfully engage with work that is not overwhelming for low-interest leaners, or rote for high-interest learners. As interest and content knowledge are often highly correlated (Hidi & Renninger, 2006), it is important that the student's prior knowledge also be considered as a factor for setting appropriate levels of challenge.

The fourth set of design principles provide recommendations for delivering science investigation or engineering design lessons that are social situated. That is, the lessons must be sensitive to the cultural and personal backgrounds of students, and leverage the power of social engagement to enhance interest development. One design principle, that relates to making appropriately challenging material is Azevedo's (2006) interest-based participation model. Here Azevedo focuses on the complexity of each individual's past experience as they relate to any learning activity. Since there are several concurrently held self-identities and interests within each individual, that Azevedo refers to as their *lines of practice*, activities can be tailored in such a way that allows individuals the opportunity to make "hooks" into the content based on their current lines of practice (Azevedo, 2015). For example, while using an intelligent tutoring system for algebra, students who were given math problems that included context that was tailored to topics they had previously indicated as interesting were more likely to get answers correct, and were more efficient in answering hard problems (Walkington 2013; effect size not available). To provide students the opportunity to make "hooks" also requires extended time and space to explore in the activity, as they may need several attempts to make connections within the content. Curriculum that is oriented to students' interest and that makes reference to the everyday life of the student can facilitate retention and reactivation of the learned content, and develop interest (Haussler & Hoffman, 2002). Specific design recommendations for providing interest-based learning opportunities in science investigation and engineering design lessons include structuring investigations and design work to allow student driven modification to the activity, and ample time to explore the investigation and design space to find what is compelling to them. Students should also be allowed to start and restart new ideas and paths to learning. As with value-based interventions, it is likely that low-interest students may need some initial support to begin any sort of engagement at all, and these supports can be faded over time.

Another method of utilizing socially situated learning is to design lessons to deliberately emphasize social connectedness through a method of canalization. Social connections support interest and learning in content by providing a shared experience and excitement for the work, access to information, and ideas about how and what to pursue next (Bergin, 2016). These social connections aid in internalizing values for the content (Deci & Ryan, 1991) through finding shared purpose, focus, and values (Rogoff, 1998). To create learning activities that promote social connections, Pressick-Kilbourn (2015) describes curating connectedness in science as *canalization*, where educators make "canals" to guide students towards finding value and relevance for science through shared experience and activity. Specific design recommendations for promoting social connectedness include creating activities that make explicit connections between school-based learning and the real worlds that the children live in (Pressick-Kilbourn, 2015; Pressick-Kilbourn & Walker, 2002), and intentionally pointing out the importance of these connections. These connections can be made through field studies and excursions within the nearby community, or by having teachers, other adults, or peers model excitement and share personal stories for activity and learning in science and engineering. Again, it is important that the attempt to make these connections are culturally appropriate, authentic, and related to the real-lives of the students.

Table 2

Design Guidelines for Developing Interest During Science Investigation and Engineering Design Activities

	Scaffolded Design Guidelines	
Lesson Design Factor	Low Interest	High Interest
Autonomy and Choice	Provide *few*, relatively *simple* choices with supports for making the choice	Fade to include more options and complex choices. Remove choice making support
	Demonstrate connections to a variety of other student interests outside of the content	Allow the student to explore aspects of the content in more depth
Relevance	Give writing prompts to *self-generate* utility value of content.	Fade to more directly highlight utility value
	Ask learner to describe *existing* personal values	Fade to describing personal value for content
	Presented by same age or older *peers* that relate to other topic interests	Fade to be presented by *experts* that relate directly to content
Relevance (cont.)	Problem context should present *broad examples* of practitioners and work in the content	
	Support *personal excursions* connecting existing skills and interest to content	Fade to support excursions for curiosity question for deeper understanding of content

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Appropriately Challenging Material	Short *procedural* directions for next steps	Fade to provide more *conceptual* hints and feedback
	Include *novel* and moderately *challenging* problems	Fade to increase novelty and present problems that are more challenging for the learner
	Express *appreciation* for difficulty of problem	Fade to less frequent appreciation
Socially Situated Activities	Support student driven modification to activities	Fade supports to provide open-ended student driven modification to activities
	Provide ample time to explore the investigation and design space to find what is compelling to them	Provide ample time to explore the investigation and design space to deeply explore problems
	Conduct field studies and excursions within the nearby community	
	Have teachers, other adults, or peers model excitement and share personal stories for activity and learning in science and engineering	
	Make connections that are culturally appropriate, authentic, and related to the real-lives of the students	

Note: These design guidelines represent *promising practices* for implementing interest development theory into science investigations or engineering design work, and have not been well tested in intervention studies.

Examples of educational activities designed using interest development. To illustrate what the implementation of these interest design recommendation might look like in real educational settings, the following three examples can be consulted as demonstrations of science investigations or engineering design work that utilize these or similar design guidelines. First, there are several studies that use *citizen science* methods (Bonney et al., 2009) for conducting science investigations. Citizen science encourages the public to participate in scientific data collection to enhance the size and scope of data available to researchers by providing some level of professional training to non-scientists who then conduct data collection in the field. By implementing citizen science methods in classroom science investigations, educators provide their students with opportunities to collect data for authentic research, in the field, from their surrounding communities. Students are supported with training for data collection, often by professional scientists, and given an opportunity to explore the data collection and analysis. Using citizen science has been found to increase interest, and self-efficacy in science, and improve science achievement (Hiller & Kitsantas, 2014).

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Another approach to using similar interest design recommendations is to utilize the Attention, Relevance, Confidence, and Satisfaction (ARCS) interest framework that focuses on student attention, relevance, confidence, and satisfaction during learning (Keller, 1987). ARCS is one of the few systematically designed educational interventions that is based on interest development theory and has been tested in the field. An example of the use of ARCS in science learning is Feng and Tuan's (2005) use of the model in an 11th grade chemistry classroom. In this study students learned about acids and bases in a series of science investigation activities. Students had multimedia and hands-on learning activities to increase their attention to the work, worked cooperatively on tests to improve their confidence, and were given positive and constructive feedback to improve their satisfaction. They were also given learning opportunities and examples that related to their own lives and interests. For example, instead of using litmus paper tests for pH, students were asked to bring in flowers to class that they thought might respond differently to pH, and were tasked with classifying unknown chemicals based on flower reactions. Feng and Tuan's implementing of the ARCS framework in a classroom led to higher motivation and achievement in chemistry when compared to a control classroom.

A third approach to using interest design recommendations is the eMpowerment, Usefulness, Success, Interest, and Caring (MUSIC) Model in engineering design by Jones, Epler, Mokri, Bryant, & Paretti (2013). In this work the authors created a college capstone problem-based design course that implemented motivational interventions from a variety of sources. Their guidelines include focusing on students feeling empowered, usefulness of the content, success, interest, and being cared about. To do this, the design course was a student centered, ill-structure problem-based learning environment that allowed students to incorporate learning from other disciplines into their activity. Students were given ample time to iterate over their designs, reflect on their work, and present their projects to industry professionals. While this study only measured student interest and motivation using questionnaires and interviews, it is a promising model for the incorporation of multiple motivational and interest design recommendations into engineering design activities.

Conclusion to Part II. Science investigations and engineering design work that incorporate design guidelines based on interest and motivation research can improve learning during these activities, and help instill a desire for the student to re-engage with the content during subsequent instruction (Hidi & Renninger, 2006). These design guidelines should be carefully scaffolded to meet the specific needs of learners at differing levels of interest in engineering and science to best promote interest and learning. However, there are few examples of this type of scaffolding in practice, and more research on the efficacy and practicality of incorporating interest scaffolds is warranted. While the examples I have provided do not explicitly scaffold based on student interest, they demonstrate how multiple interest development design guidelines can be incorporated into science investigation or engineering design activities.

Part III: Is there any information about particular strategies that work differently for students from specific populations or backgrounds?

Many of the strategies described in earlier sections of this paper have been successfully implemented to improve interest, motivation, and learning for specific demographic groups including women, and minorities. In their review of motivation interventions, Rosenzweig & Wigfield (2016) found that interventions targeting women have been effective, but it is hard to say if moderators exist (e.g. age) or pre-existing low motivation was cause of response. They also found that most studies included in their review involved European American middle-class students, and that very few researchers who used diverse samples actually measured whether race, ethnicity, or socio-economic status impacted the effectiveness of their interventions. There is evidence that suggests that it is not usually the case that underrepresented students drop out of certain STEM career tracks because they have lower ability in those subjects, rather it is often because they have lower value, interest, or self-efficacy for them (Wang, Eccles, and Kenny, 2013). Thus, it important to continue focusing on improving interest and motivation for underrepresented groups, and to further research that examines the complex interaction between gender, race, and other mediating factors on these constructs.

An additional factor to be addressed for those groups traditionally underrepresented in science and engineering are persistent stereotypes about the inclusion of females (Buck, Plano Clark, Leslie-Pelecky, Cerda, & Lu, 2008) and minorities (Museus, Palmer, Davis & Maramba, 2011) in these fields. Models for improving our understanding of the experience of underrepresented groups in science and engineering can help to alleviate this problem. For example, Varelas, Martin, and Kane (2012) provide the content learning and identity (CLIC) framework for understanding how African-American students simultaneously develop multiple identities as they learn in science and mathematics classrooms. In this framework, there is equal emphasis placed on the student's developing academic, content based (e.g. doers of science), and racial identities. One example of this type of work is a study by Calabrese-Barton, Tan & Rivet (2008), who demonstrate how minority girls adapt science participation in order to engage in science in ways that fulfill their multiple identities. By incorporating models that directly acknowledge the intersection of multiple identities, we may be able to create a clearer picture of how to overcome the negative impact of barriers such as stereotypes in supporting interest, motivation, and learning in science and engineering.

One method of attacking the common stereotypical image of white males in science and engineering fields is to provide role models in science and engineering. Role models for students can help inspire them to engage and achieve in science and engineering disciplines, and see themselves in these roles (Stout, Dasgupta, Hunsinger, & McManus, 2011). While generally, it is thought that matching the role model's demographics (race, gender, etc.) to the student's demographics is the best approach, this is a complex intervention with several key mediators to successful implementation. Researchers have found that rather than simply matching student demographics, presenting science and engineering as disciplines made of a multitude of real and diverse people is effective in developing interest and motivation in these fields (Cheryan, Siy, Vichayapai, Drury & Kim, 2011). In a study of role models for girls, Buck et al. (2008) reported that students want both male and female role models from a variety of racial backgrounds that they can make personal and real connections with, rather than being provided role models that are distanced exemplars of scientists. Betz and Sekaquaptewa (2012) found that presenting overtly feminine STEM role models had a negative effect on promoting interest in science and math for low-interest girls. Moore (2006) also points out that there is also an important part for family role models to play in developing interest in STEM areas. By providing role models, we open student eyes to the possibility of their authentic involvement in science and engineering practices. This can aid students in seeing congruence between their content based identity as a doer of science and engineering, and other identities such as gender or racial identities.

However, addressing underrepresented students' ability to see themselves in the role of a scientist or engineer tackles only one, internal, barrier to improving their motivation to persist in a pursuit of learning in these fields. Larger societal issues (e.g. persistent gendered and racial stereotypes about lack of ability in science and engineering) play a key role in underrepresented student motivation that create external barriers for these students, and these external barriers must be addressed (For a comprehensive review of this issue see DeCuir-Gunby, & Schutz, 2017). For underrepresented students, persistence in science and engineering learning requires "substantial financial resources, as well as ongoing social and educational support, to make the transition from interest in engineering to a college major and a career in an engineering field" (Bystydzienski, Eisenhart, & Bruning, 2015, pg. 94). In relation to in-the-moment classroom learning, adding social supports may be one area classroom educators can focus on to remove external barriers to success for underrepresented students. Teachers, as well as parents and peers, can resist setting lowered expectations and offer encouragement to engage in science and engineering learning as social supports for underrepresented students (Yu, Corkin, & Martin, 2017). Classroom environments must also actively pursue *positive intergroup relations*, where all individuals are given equal status, support from authority, and a voice in creating common goals (Kumar, Karabenick, & Warnke, 2017). An example of an intervention study to support underrepresented groups in science and engineering is the Female Recruits Explore Engineering (FREE) and Pathways Project (Bystydzienski, Eisenhart, & Bruning, 2015). In this work in an after-school program, female high-school students were provided guided exposure to engineering, conducted their own engineering projects, were given access to peer and mentor social connections outside of the classroom, and received college mentoring over the course of three years. These students were found to have increased numbers of engineering and STEM majors in college compared to peers not in the intervention. Interventions like the FREE project demonstrate the power of external support and removal of barriers for increasing the motivation for underrepresented students in science and engineering. However, I have provided only a small review of addressing the internal and external barriers that reduce motivation and learning for underrepresented groups, and it is crucial that these areas be examined more closely in making curricular recommendations in the future.

Part IV: Intrinsic v. Extrinsic Motivation

In this section I examine the role of extrinsic motivators while learning in science and engineering. Extrinsic motivators were once thought to be detrimental to long-term student motivation and have lasting negative consequences on learning, because they undermine intrinsic motivation (e.g. Deci, Koestner, and Ryan, 1999). However, there is a growing belief that intrinsic and extrinsic motivational factors can exist simultaneous and their intersection can be beneficial for motivation and learning (Harackiewicz, Barron, Pintrich, Elliot, & Thrash, 2002). For example, students may attempt to pursue learning content material deeply to master course content and grow their knowledge of the subject (i.e. are intrinsically motivated), and simultaneously attempt to maximizing their course grade (i.e. are extrinsically motivated) during learning in academic coursework. Researcher have suggested that extrinsic motivators such as rewards and grade may actually have important benefits to promote motivation, because they may be necessary to motivate students with very low interest in the activity to engage at all (Hidi & Harackiewicz, 2000). Interest development theories deliberately include externally triggering situational interest, through environmental supports such as rewards, as an initial step in developing individual interest (Renninger & Su, 2012).

There is currently debate about the use of extrinsic motivation in education (Linnenbrink-Garcia & Patall, 2016), but many experts have begun to see both as beneficial for academic achievement and motivation. Unfortunately, most work in this area has been conducted in a correlational manner, and no interventions explicitly targeting both intrinsic and extrinsic motivators appear to have been reported. Therefore, it is difficult to settle the debate. My recommendation in this area is that intrinsic motivation should still be a major focus for educators to improve student learning, but the use of extrinsic motivators (e.g. rewards, reinforcements, exciting environments) should not be vilified or dismissed. As with much of the work in motivation research, an increased number of experimental studies is needed to further explore the relationship between intrinsic and extrinsic motivators, and how to best utilize these to promote learning.

Part V: Conclusion

There is a wealth of theoretical models describing how to develop and maintain interest and motivation in science and engineering, and how this increased motivation is linked to increased learning and achievement. However, there is also a significant lack of experimental evidence comparing motivational interventions to control conditions to demonstrate the efficacy of motivational interventions for improved learning. Some evidence does exist to suggest that motivational interventions for improving a student's intelligence beliefs and intrinsic motivation for performing and achieving in science and engineering are effective (see Part I). There are also several design guidelines from interest development research that can be integrated into science and engineering learning environments to effectively increase learning during investigation and design activities (see Part II). The incorporation of these guidelines can be a useful starting point for researchers to evaluate the effectiveness of these interventions in science and engineering, and to explore the nuanced differences for appropriate application of interest and motivation interventions between specific disciplines in science and engineering. For practitioners, these guidelines can be integrated as motivational support for their students during science investigations and engineering design work. There is also a need to improve the representation of women and minorities in science and engineering that necessitates developing their interest and motivation in these fields, and these groups clearly have specific motivational needs. However, this is a complex issue that requires nuanced longitudinal studies, and theoretical frameworks sensitive to examining factors internal and external that might reduce participation and persistence of underrepresented groups in science and engineering.

The growing body of evidence that demonstrates intervention methods can help improve interest and motivation, and learning and achievement in science and engineering is promising. Increasing interest and achievement at the 6-12 level can spur increases in pursuing science and engineering related majors and subsequently careers at the next levels, because more students will have the *desire* to make this pursuit and will have the *knowledge and skills* necessary to be successful. Success in 6-12 science and engineering can also have a major impact on a student's educational experience regardless of whether they pursue careers in these fields. Not all students will, or should, aspire to a science or engineering career, yet these classes are required at nearly every stage of formal education, and literacy in science and engineering is increasingly important for a well-informed public. Improving interest and learning in science and engineering for these students can positively impact their relationship with formal education, their literacy and self-efficacy in these areas, and provide more tangible benefits such as improved GPA, ACT/SAT scores, and placement in college courses.

References

Acee, T. W., & Weinstein, C. E. (2010). Effects of a value-reappraisal intervention on statistics students' motivation and performance. *The Journal of Experimental Education, 78*(4), 487-512.

Ames, C. (1992). Classrooms: Goals, structures, and student motivation. *Journal of Educational Psychology, 84*, 261-271.

Azevedo, F. S. (2006). Personal excursions: Investigating the dynamics of student engagement. *International Journal of Computers for Mathematical Learning, 11*(1), 57-98.

Azevedo, F. S. (2013). The tailored practice of hobbies and its implication for the design of interest-driven learning environments. *Journal of the Learning Sciences, 22*(3), 462-510.

Azevedo, F. S. (2015). Sustaining interest-based participation in science. In K. A. Renninger, M. Nieswandt, & S. Hidi. *Interest in mathematics and science learning.* (pp. 281-297). Washington, DC: American Educational Research Association.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs, NJ: Prentice-Hall.

Bandura, A. (1997). *Self-efficacy. The exercise of control*. New York: W.H.Freeman and Company.Emory University.

Bereby-Meyer, Y., Assor, A., & Katz, I. (2004). Children's choice strategies: The effect of age and task demands. *Cognitive Development, 19*, 127–146.

Bergin, D. A. (2016). Social influences on interest. *Educational Psychologist, 51*(1), 7-22.

Betz, D. E., & Sekaquaptewa, D. (2012). My fair physicist? Feminine math and science role models demotivate young girls. *Social Psychological and Personality Science*, *3*, 738–746.

Blackwell, L., Trzesniewski, K., & Dweck, C.S. (2007). Implicit Theories of Intelligence Predict Achievement Across an Adolescent Transition: A Longitudinal Study and an Intervention. *Child Development, 78*, 246-263.

Blumenfeld, P. C., Kempler, T. M., & Krajcik, J. S. (2006) Motivation and cognitive engagement in learning environments. In K. Sawyer (Ed.) *The Cambridge Handbook of the Learning Sciences (1st Edition, pp. 475 - 488)* Cambridge University Press: New York.

Bobbitt-Nolen, S. B., Ward, C. J. (2008). Sociocultural and situative approaches to studying motivation. In M. L. Maehr, S. A. Karabenick & T. C. Urdan (Eds.) *Social Psychological Perspectives Advances in Motivation and Achievement,* (Vol. 15, pp. 425 - 460). Bingley, UK: Emerald Group Publishing.

Bong, M., Lee, S. K., & Woo, Y. (2015). The roles of interest and self-efficacy in the decision to pursue mathematics and science. In K. A. Renninger, M. Nieswandt, & S. Hidi. *Interest in mathematics and science learning.* (pp. 33 - 48). Washington, DC: American Educational Research Association.

Bonney, R., Cooper, C., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K., & Shirk, J. (2009). Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. *BioScience, 59*(11), 977-984.

Brophy, J. (2008). Developing students' appreciation for what is taught in school. *Educational Psychologist, 43*(3), 132-141.

Brown, P., Mccord, R., Matusovich, H., & Kajfez, R. (2014). The use of motivation theory in engineering education research: A systematic review of literature. *European Journal of Engineering Education*, *23*, 1-20.

Buck, G., Plano Clark, V. L., Leslie-Pelecky, D., Lu, Y., Cerda-Lizarraga, P. (2008) Examining the cognitive processes used by adolescent girls and women scientists in identifying science role models: A feminist approach. *Science Education*, *94*(4), 688-707.

Bystydzienski, J. M., Eisenhart, M., & Bruning, M. (2015). High school is not too late: Developing girls' interest and engagement in engineering careers. *The Career Development Quarterly, 63*, 88 – 95.

Calabrese-Barton, A., Tan, E., Rivet, A. (2008). Creating hybrid spaces for engaging school science among urban middle school girls. *American Educational Research Journal, 45*(1), 68-103.

Cheryan, S., Siy, J. O., Vichayapai, M., Drury, B. J., & Kim, S. (2011). Do female and male role models who embody stem stereotypes hinder women's anticipated success in STEM? *Social Psychological and Personality Science 2*(6), 656 – 664.

Crippen, K. J., & Earl, B. L. (2004). Considering the efficacy of web-based worked examples in introductory chemistry. *Journal of Computers in Mathematics and Science Teaching, 23*(2), 151–167.

Crippen, K. J., & Earl, B. L. (2007). The impact of web-based worked examples and self-explanation on performance, problem solving, and self-efficacy. *Computers & Education, 49*, 809–821.

Deci, E. L., Koestner, R., & Ryan, R. M. (1999). A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation. *Psychological Bulletin, 125*, 627-688.

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*. New York: Plenum.

Deci, E. L., & Ryan, R. M. (1991). A motivational approach to self: Integration in personality. In R. Dienstbier (Ed.), *Nebraska symposium on motivation: Vol. 38, Perspectives on motivation* (pp. 237-288). Lincoln: University of Nebraska Press.

DeCuir-Gunby, J. T., & Schutz, P. A. (2017) *Race and Ethnicity in the Study of Motivation in Education.* New York: Routledge.

Dweck, C.S. (2008). Mindsets and math/science achievement. Commissioned paper prepared for the *Carnegie Corporation of New York-Institute for Advanced Study Commission on Mathematics and Science Education. Retrieved from* http://www.growthmindsetmaths.com/uploads/2/3/7/7/23776169/mindset_and_math_science_achievement_-_nov_2013.pdf

Dweck, C. S., Leggett, E. L. (1988). A social-cognitive approach to motivation and personality. *Psychological Review 95*(2), 256–273.

Durik, A. M., Hulleman, C. S., & Harackiewicz, J. M. (2015). One size fits some: Instructional enhancements to promote interest. In K. A. Renninger, M. Nieswandt, & S. Hidi. *Interest in mathematics and science learning.* (pp. 39 - 62). Washington, DC: American Educational Research Association.

Cerasoli, C. P., Nicklin, J. M., & Ford, M. T. (2014). Intrinsic motivation and extrinsic incentives jointly predict performance: A 40-year meta-analysis. *Psychological Bulletin, 140(4),* 980-1008.

Fulmer, S. M., & Frijters, J. C. (2011). Motivation during an excessively challenging reading task: The buffering role of relative topic interest. *The Journal of Experimental Education, 79*, 185-208.

Gaspard, H., Dicke, A., Flunger, B., Brisson, B. M., Häfner, I., Nagengast, B., & Trautwein, U. (2015). Fostering adolescents' value beliefs for mathematics with a relevance intervention in the classroom. *Developmental Psychology, 51*(9), 1226-1240.

Grant, H. & Dweck, C.S. (2003). Clarifying achievement goals and their impact. *Journal of Personality and Social Psychology, 85*, 541-553

Haussler, P., & Hoffmann, L. (2002). An intervention study to enhance girls' interest, self-concept, and achievement in physics classes. *Journal of Research in Science Teaching, 39*, 870–888.

Harackiewicz, J. M., Barron, K. E., Pintrich, P. R., Elliot, A. J., & Thrash, T. M. (2002). Revision of achievement goal theory: Necessary and illuminating. *Journal of Educational Psychology, 94*(3), 638-645.

Harackiewicz, J., Rozek, C., Hulleman, C., & Hyde, J. (2012). Helping parents to motivate adolescents in mathematics and science. *Psychological Science, 23*(8), 899-906.

Hidi, S. & Harackiewicz, J. (2000). Motivating the academically unmotivated: A critical issue for the 21st century. *Review of Educational Research, 70*(2), 151-179.

Hidi, S., & Renninger, K. A. (2006). The four phase model of interest development. *Educational Psychologist, 41*, 111–127.

Hiller, S. E., & Kitsantas, A. (2014). The effect of a horseshoe crab citizen science program on middle school student science performance and stem career motivation. School Science and Mathematics, 114, 302– 311.

Hong, H., & Lin-Siegler, X. (2012) How learning about scientists' struggles influences students' interest and learning in physics. *Journal of Educational Psychology 104*(2). 469-484.

Hulleman, C., & Barron, K. E. (2016). Motivation interventions in education: Bridging theory, research, and practice. In L. Corno & E. M. Anderman (Eds.), *Handbook of Educational Psychology, (3rd Ed., pp. 160 – 171)*. Routledge, Taylor and Francis: New York, NY.

Hulleman, C. S., & Harackiewicz, J. M. (2009). Promoting interest and performance in high school science classes. *Science, 326*, 1410–1412.

Järvelä, S., & Renninger, K. A. (2014). Designing for learning: Interest, motivation, and engagement. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (2nd ed., pp. 358-376). New York, NY: Cambridge University Press.

Jones, B. D., Epler, C. M., Mokri, P. , Bryant, L. H. , & Paretti, M. C. (2013). The effects of a collaborative problem-based learning experience on students' motivation in engineering capstone courses. *Interdisciplinary Journal of Problem-Based Learning, 7*(2), 34-71.

Kashdan, T. B., & Silvia, P. J. (2009). Curiosity and Interest: The Benefits of thriving on novelty and challenge. In S. J. Lopez and C. R. Snyder (Eds.) *The Oxford Handbook of Positive Psychology* (pp. 367-374). Oxford University Press: Oxford.

Katz, I., & Assor, A. (2007). When choice motivates and when it does not. *Educational Psychology Review 19,* 429-442.

Keller, J. M. (1987). Development and use of the ARCS model of instructional design. *Journal of instructional development, 10*(3), 2-10.

Kumar, R., Karabenick, S. A., Warnke, J. H. (2017). Role of culture and proximal minority/majority status in adolescent identity negotiations. In J.T. DeCuir-Gunby & P. A. Schutz (Eds.) *Race and Ethnicity in the Study of Motivation in Education (pp. 152 - 167)*. New York: Routledge.

Krapp, A., & Prenzel, M. (2011). Research on interest in science: Theories, methods, and findings. International journal of science education, 33(1), 27-50.

Linnenbrink-Garcia, L., Patall, E. A. (2016). Motivation. In L. Corno & E. M. Anderman (Eds.), *Handbook of Educational Psychology* (3rd. Ed., pp. 91-103). New York: Rutledge.

Lazowski, R. A., & Hulleman, C. S. (2015). Motivation interventions in education: A meta-analytic review. *Review of Educational Research 86*(2), 602-640.

Malone, T. W., & Lepper, M. R. (1987). Making learning fun: A taxonomy of intrinsic motivations for learning. *Aptitude, Learning, and Instruction*, *3*, 223-253.

Miyake, A., Kost-Smith, L. E., Finkelstein, N. D., Pollock, S. J., Cohen, G. L., & Ito, T. A. (2010). Reducing the gender achievement gap in college science: A classroom study of values affirmation. Science, 330, 1234–1237.

Montfort, D. B., Brown, S., & Whritenour, V. (2013) Secondary students' conceptual understanding of engineering as a field. *Journal of Pre-College Engineering Education Research, 3*(2).

Moore, James L., III. (2006). A Qualitative Investigation of African American Males' Career Trajectory in Engineering: Implications for Teachers, School Counselors, and Parents. *Teachers College Record, 108*(2), 246-266.

Museus, S. D., Palmer, R. T., Davis, R. J., & Maramba, D. C. (2011). Special issue: Racial and ethnic minority students' success in STEM education. *ASHE Higher Education Report, 36*(6), 1-140.

Patall, E. A. (2013). Constructing motivation through choice, interest, and interestingness. *Journal of Educational Psychology 105*(2), 522-534.

Patall, E. A., Cooper, H., & Wynn, S. R. (2010). The effectiveness and relative importance of choice in the classroom. *Journal of Educational Psychology, 102*(4), 896.

Paunesku, D., Walton, G. M., Romero, C., Smith, E. N., Yeager, D. S., & Dweck, C. S. (2015). Mind-set interventions are a scalable treatment for academic underachievement. *Psychological Science 26*(6), 784-793.

Pressick-Kilborn, K. (2015). Canalization and connectedness in the development of science interest. In K. A. Renninger, M. Nieswandt, & S. Hidi. *Interest in mathematics and science learning.* (pp. 353-368). Washington, DC: American Educational Research Association.

Pressick-Kilborn, K., & Walker R. (2002). The social construction of interest in a learning community. *Research on Sociocultural Influences On Motivation And Learning*, *2*, 153-182.

Puntambekar, S., & Hübscher, R. (2005). Tools for scaffolding students in a complex learning environment: what have we gained and what have we missed? *Educational Psychologist, 40*(1), 1-12.

Renninger, K. A., & Hidi, S. (2011). Revisiting the conceptualization, measurement, and generation of interest. *Educational Psychologist 46*(3), 168-184.

Renninger, K. A., Nieswandt, M., Hidi, S. (2015). *Interest in mathematics and science learning.* Washington, DC: American Educational Research Association.

Renninger, K. A. & Su, S. (2012). Interest and its development. In R. Ryan (Ed.), *Oxford Handbook of Motivation* (pp. 167-187). New York: Oxford University Press.

Rozek, C. S., Svoboda, R. C., Harackiewicz, J. M., Hulleman, C. S., & Hyde, J. S. (2017). Utility-value intervention with parents increases students' STEM preparation and career pursuit. *Proceedings of the National Academy of Sciences 114*(5), 909 – 914.

Rosenzweig, E., & Wigfield, A. (2016). STEM Motivation Interventions for Adolescents: A Promising Start, but Further to Go. *Educational Psychologist, 51*(2), 1-18.

Senechal, E. (2007). Environmental justice in Egleston Square. In D. Gruenewald & G. Smith (Eds) *Place-based education in an era of globalization: Local diversity* (Mahwah, NJ, Erlbaum).

Silvia, P.J. (2012). Curiosity and motivation. In R. M. Ryan (Ed.) *The Oxford Handbook of Human Motivation* (pp. 157 – 166). Oxford University Press: Oxford.

Stout, J. G., Dasgupta, N., Hunsinger, M., & McManus, M. (2011). STEMing the tide: Using ingroup experts to inoculate women's self-concept and professional goals in science, technology, engineering, and mathematics (STEM). *Journal of Personality and Social Psychology, 100*, 255–270.

Sukariyah, M. B., & Assaad, G. (2014). The effect of attribution retraining on the academic achievement of high school students in mathematics. In *Global Conference on Contemporary Issues in Education, GLOBE-EDU 2014*, Las Vegas, NV, 345 – 351.

Sung, H., & Hwang, G. (2013). A collaborative game-based learning approach to improving students' learning performance in science courses. *Computers & Education 63*. 43-51.

Walkington, C. (2013). Using learning technologies to personalize instruction to student interests: The impact of relevant contexts on performance and learning outcomes. *Journal of Educational Psychology, 105*(4), 932-945.

Weiner, B. (1985). An attributional theory of achievement motivation and emotion. *Psychological Review, 92*(4), 548-573.

Wigfield, A., & Eccles, J. S. (2000). Expectancy–value theory of achievement motivation.

Contemporary Educational Psychology, *25*(1), 68-81.

Wyss, V. L., Heulskamp, D., & Siebert, C. J. (2012). Increasing middle school student interest in STEM careers with videos of scientists. *International Journal of Environmental & Science Education*, *7*(4), 501–522.

Yu, S. L., Corkin, D. M. & Martin, J. P. (2017). STEM motivation and persistence among underrepresented minority students: A social cognitive perspective. In J.T. DeCuir-Gunby & P. A. Schutz (Eds.) *Race and Ethnicity in the Study of Motivation in Education (pp. 67 – 81)*. New York: Routledge.

Ziegler, A., & Heller, K. A. (2000). Effects of an attribution retraining with female students gifted in physics. *Journal for the Education of the Gifted*, *23*, 217–243.

Ziegler, A., & Stoeger, H. (2004) Evaluation of an attributional retraining (modeling technique) to reduce gender differences in chemistry instruction. *High Ability Studies 15*(1), 63-83.

[i] For cross-comparison purposes, I report all effect sizes using Cohen's d. Since there are several methods of statistical testing in each of the intervention studies described, I use the compute.es package in R to calculate effect sizes that are not immediately reported as Cohen's d. For these tests, a small effect is 0.2, a medium effect is 0.5, and a large effect is 0.8. When the results of a study do not include enough information to calculate an effect size, I note this in parenthesis as *effect size not available*.

[ii] Curiosity is an additional construct often associated with motivational variables, and in particular with interest. Like interest, curiosity can be thought of as a state induced by environmental factors, such as novelty and complexity, as well as a more stable trait (Silvia, 2012). However, curiosity is most often considered as an emotional factor (Renninger & Su, 2012), whereas most motivational variables consist of both emotional/affective and cognitive components. Inducing curiosity may have positive motivational benefits such as eliciting an approach, as opposed to avoidance, goal mentality, or inciting initial engagement in material that may not otherwise be pursued by a student. To date there are no intervention studies I am aware of that utilizes this approach, and the literature on curiosity recognizes this deficiency (Kashdan & Silvia, 2008). Much of the theoretically prescribed methods of inducing curiosity (e.g. novelty and challenge) are included in the recommendations in section II.

[iii] The measurement of high and low interest is a complex and challenging task that does not have a normative quantitative measurement tool or a consistent method of measurement. Many examples of self-report surveys exist, but these only serve to demonstrate relative interest levels or growth in interest. The use of qualitative identification of interest levels is also quite common. For a review see Renninger & Hidi (2011).