Examining STEM Diagnostic Exam Scores and Self-Efficacy as Predictors of Three-Year STEM Psychological and Career Outcomes

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Abstract

In this research-based paper, we explore the relationships among Rice University STEM students' high school preparation, psychological characteristics, and career aspirations. Although greater high school preparation in STEM coursework predicts higher STEM retention and performance in college [1], objective academic preparation and college performance do not fully explain STEM retention decisions, and the students who leave STEM are often not the lowest-performing students [2]. Certain psychosocial experiences may also influence students' STEM decisions. We explored the predictive validity of 1) a STEM diagnostic exam as an objective measure of high school science and math preparation and 2) self-efficacy as a psychological measure on long-term (three years later) STEM career aspirations and STEM identity of underprepared Rice STEM students. University administrators use diagnostic exam scores (along with other evidence of high school underpreparation) to identify students who might benefit from additional support. Using linear regression to explore the link between diagnostic exam scores and self-efficacy, exam scores predicted self-efficacy a semester after students' first semester in college; exam scores were also marginally correlated with self-efficacy three years later. Early STEM career aspirations predicted later career aspirations, accounting for 21.3% of the variance of career outcome expectations three years later (β=.462, p=.006). Scores on the math diagnostic exam accounted for an additional 10.1% of the variance in students' three-year STEM career aspirations (p=.041). Self-efficacy after students' first semester did not predict future STEM aspirations. Early STEM identity explained 28.8% of the variance in three-year STEM identity (p=.001). Math diagnostic exam scores accounted for only marginal incremental variance after STEM identity, and self-efficacy after students' first semester did not predict three-year STEM aspirations. Overall, we found that the diagnostic exam provided incremental predictive validity in STEM career aspirations after students' sixth semester of college, indicating that early STEM preparation has long-lasting ramifications for students' STEM career intentions. Our next steps include examining whether students' diagnostic exam scores predict STEM graduation rates and final GPAs for science and math versus engineering majors.

Introduction

Adequate high school preparation in science and math is integral for both high performance in STEM (science, technology, engineering, and math) classes in college (e.g. [3,4]) and STEM major retention (e.g. [5,6]). Students from less academically challenging high schools are particularly vulnerable to lower college performance and retention, because STEM college courses, which require critical thinking and problem solving, are very different from science and math classes at weaker high schools [7]. Underprepared students are also more likely to be taught science and math by teachers underqualified in STEM and are less likely to have access to challenging math and science courses in high school [8,9]. The less prepared a matriculating student is for science and math coursework, the more "catch-up" they may have to do to arrive at the same base level of course knowledge expected by college professors, in addition to learning new course material [10].

The long-term effect of high school preparation on college student engineering outcomes is considerable. For example, high school GPA and SAT quantitative scores were a strong predictor of students' odds of graduating as an engineering major across six universities [11]. In another study of undergraduate degree recipients who originally majored in engineering, transferring more STEM than non-STEM AP credits from high school and having higher quantitative standardized test scores predicted engineering degree attainment, even controlling for undergraduate cumulative GPA [12].

Expectancy-Value Framework

Both individual characteristics and social factors influence STEM trajectories [13]. Using the expectancy-value achievement model by Eccles and Wigfield [14], we frame these characteristics as part of a cohesive framework designed to reflect the myriad factors that contribute to students' ultimate academic choices. In the expectancy-value framework, three overarching factors contribute to educational and career choices: 1) psychological factors, 2) biological factors, and 3) socialization factors. These three components jointly predict achievement behavior and choices (e.g. selection of a major). For the purposes of this paper, we focus primarily on psychological factors, although we explore the influence of social factors as well. See Figure 1 below for the adapted model.

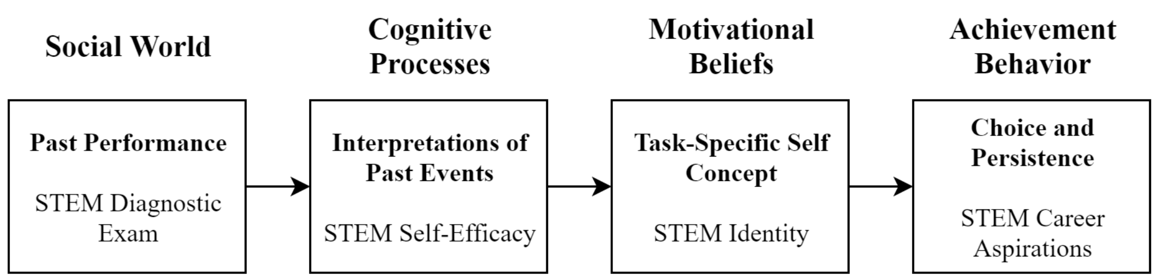

Figure 1. Adapted model of Eccles and Wigfield's expectancy-value framework

Past Performance

For this study, we operationalize past performance as scores on the university's internally developed STEM diagnostic exam. The exam is designed to assess underpreparedness among incoming STEM students to identify students who might need extra resources and institutional support. The exam covers advanced math, chemistry, and physics topics and is designed to test students' ability to apply conceptual knowledge of these topics to complex word problems. A validation study found that this exam predicts incremental variance in STEM course grades beyond standardized test scores [15]; further details on exam content are outlined in a related scale development study [16]. This measure is discussed further in the Method section.

Interpretations of Past Events

Students' *self-efficacy* is their belief in their ability to perform tasks as well as desired [10]. Self-efficacy informs students about desirable courses of action and increases the likelihood that they will act [17]. People tend to form goals and engage in tasks aligned with those activities in which they feel the most efficacious [18]. Academic self-efficacy beliefs may be the result of perceptions of past performance in academic domains [19].

Reflecting the predictions of the expectancy-value model, high school STEM preparation may predict college STEM self-efficacy [20]. Although the students in this study do not receive their diagnostic exam scores, we anticipate the process of taking this difficult exam will inform students' self-perceptions of preparedness and confidence in their ability to perform well in future STEM courses. Understanding how both academic preparation and self-efficacy impact STEM college students psychologically and through their behavioral intentions may help researchers better understand how and why students persist in STEM.

Task-Specific Self-Concept

Eccles [21] discussed the impact that both social identities and personal identities have on the later stages of the expectancy-value framework. Personal identities are individuals' highly valued perceptions of themselves and their understanding of their own behaviors and cognitions; social identities are individuals' highly valued perceptions of their ties to personally important social groups, whether that be families, communities, or demographic groups (or any other social collective) [21].

We conceptualize *STEM identity* in this model as students' self-concept, encompassing both a social and a personal identity. As a social identity, it reflects the extent to which a student feels that they are a member of a broader STEM community and is, in turn, seen as belonging in STEM by other members [22]. As a personal identity, STEM identity can be viewed as a dynamic construct consisting of students' beliefs, goals, self-perceptions, and perceived courses of action [23]. In academic settings, identity has been shown to predict learning, engagement with class content, and decisions to pursue specific disciplines in the future [22].

Choice and Persistence

STEM career aspirations are students' current intentions of having a STEM career when they graduate. STEM career aspirations tend to decline over time; however, there are clear individual differences in changes in STEM career plans, which fluctuate for many students [24]. In the expectancy-value model, we frame career aspirations as an achievement behavior choice that follows the development of STEM identity and precedes behavior (i.e. pursuing a STEM-related career).

Current Study

We explore the relationships among objective STEM preparation and STEM self-efficacy as predictors and STEM identity and STEM career aspirations as outcomes. First, we expect to see the strong link predicted by the expectancy-value framework between past academic performance and early college self-efficacy.

> *Hypothesis 1:* Students' diagnostic exam scores will positively predict their first-semester STEM self-efficacy.

The expectancy-value framework predicts that certain stages of the model (such as self-efficacy) partially mediate the relationship between more distal constructs (e.g. high school preparation) and more proximal constructs (e.g. STEM identity); however, it predicts that some direct relationship exists [14].

Further, based on the research suggesting the impact of high school preparation on STEM major choices, we expect the influence of high school preparation to persist through students' time in college. We hypothesize that STEM preparation will impact students' beliefs about whether they fit the identity of a STEM student (i.e. STEM identity) and whether they plan to pursue a STEM career (i.e. STEM career aspirations).

> *Hypothesis 2:* Students' diagnostic exam scores will predict their three-year STEM identity.

> *Hypothesis 3:* Students' diagnostic exam scores will predict their three-year STEM career aspirations.

Finally, based on the predictions of the model of self-efficacy predicting later achievement-related choices, we expect first-semester self-efficacy to predict students' identity and career aspirations three years later.

> *Hypothesis 4:* Students' early STEM self-efficacy will predict their three-year STEM identity.

> *Hypothesis 5:* Students' early STEM self-efficacy will predict their three-year STEM career aspirations.

Method

Participants

Participants were 86 third-year college students at Rice University who had declared a STEM major when matriculating and were initially identified as being underprepared in STEM based on their high school STEM coursework, SAT and SAT II scores, and diagnostic exam scores. The matriculating majors of students were engineering (n=31), computer science (n=11), mathematics (n=8), and natural science (n=36). Because Rice is an extremely selective university (the Fall 2019 acceptance rate was less than 10% [25]), these students were highly academically successful in high school despite being relatively underprepared in STEM coursework.

Procedure

Participants completed optional surveys at the end of every semester, with compensation of $20 per survey. Mean survey response rates were approximately 60%.

Measures

STEM Diagnostic exam. The exam was mandatory and was taken online during the summer before students matriculated. The average number of questions correct (out of 14 possible) for students who were not identified as potentially needing further support (n=523) was 7.40; the average score for students who were identified for extra support (n=86) was 4.93.

STEM self-efficacy. Items were adapted from the Motivated Strategies for Learning Questionnaire [26] to make them STEM-domain specific. Students were instructed to respond according to the STEM field in which they were currently the most interested. This was an 8-item measure from 1 (strongly disagree) to 7 (strongly agree). Items included “I am sure I can do an excellent job on the problems and tasks assigned for my STEM courses” and “I'm certain I can understand the ideas taught in my STEM courses.” These items were assessed after students’ first semester in college (i.e. early self-efficacy), after their second semester, and after their sixth semester. Cronbach’s alpha was .92 for early self-efficacy. In scale development, Cronbach’s alpha, which reflects the reliability of a scale, values of .70 or higher (and preferably .80 or higher) are generally viewed as acceptable [27].

STEM identity. Items were adapted from the Academic Self-Description Questionnaire II [28], as well as a STEM intrinsic value scale [14], to make them STEM-specific. This was a 10-item measure from 1 (strongly disagree) to 5 (strongly agree). Items included “I consider myself to be a person who does well in STEM disciplines” and “I'm proud of my ability to do well in STEM courses.” These items were assessed after students’ first semester in college and at the end of students’ sixth semester in college. Alpha was .82 for early STEM identity.

STEM career aspirations. Items were adapted from the Scientific Possible Selves measure [29]. This was a 5-item measure from 1 (strongly disagree) to 5 (strongly agree). Items included “I expect to have a strong professional STEM career in the future” and “I have always hoped to have a STEM job one day.” These items were assessed after students’ first semester in college and after students’ sixth semester in college. Alpha was .80 for early STEM career aspirations.

Statistical Methods

Correlation, reliability, and multiple linear regression analyses were conducted in SPSS version 23.

Results

First, we explored the link between diagnostic exam scores and self-efficacy after students’ first semester (i.e. early self-efficacy) in college. We found that diagnostic exam scores predicted self-efficacy a semester after students’ first semester in college (r=.287, p=.043), supporting Hypothesis 1. Diagnostic exam scores were also marginally correlated (r=.246, p=.103) with self-efficacy three years later.

Next, we used linear regression to analyze the contribution of both diagnostic exam scores and self-efficacy in predicting STEM identity three years later. Unsurprisingly, early STEM identity predicted later STEM identity, explaining 28.8% of the variance in three-year STEM identity (β=.537, p=.001). When math diagnostic exam scores and early self-efficacy were added to the model, exam scores accounted for only marginal incremental variance (R^2 change=.057) beyond STEM identity (early STEM identity β=.468, p=.027; math diagnostic scores β=.245; p=.127), which did not support Hypothesis 2. Self-efficacy after students' first semester did not predict three-year STEM aspirations, which did not support Hypothesis 4.

Finally, we analyzed the contribution of both diagnostic exam score and early self-efficacy in predicting STEM career aspirations three years later. As with STEM identity, early STEM career aspirations predicted later career aspirations, accounting for 21.3% of the variance in career aspirations three years later (β=.462, p=.006). Scores on the math diagnostic exam accounted for an additional 10.1% of the variance in students' three-year STEM career aspirations (early career aspirations β=.405, p=.012; math diagnostic scores β=.322, p=.041), providing support for Hypothesis 3. Self-efficacy after students' first semester did not predict future STEM aspirations, which did not support Hypothesis 5. See Table 1 below for a summary of these findings.

Table 1

Regression Models of STEM Identity and Career Aspirations Outcomes

Model	**ΔR^2**	**β**
Three-Year STEM Identity		
Step 1	.288*	
Early STEM Identity		.537*
Step 2		
Early STEM Identity	.057	.468*
Math Diagnostic Exam		.245
Early Self Efficacy		.012
Total R^2	.345*	
Three-Year STEM Career Aspirations		
Step 1		
Early STEM Career Aspirations	.213**	.462**
Step 2		
Early STEM Career Aspirations	.101*	.405*
Math Diagnostic Exam		.322*
Early Self Efficacy		.247
Total R^2	.314*	

Note: *p<.05 **p<.01

Discussion

Using Eccles and Wigfield's expectancy-value theory [14], we explored whether the expected associations based on the framework existed in our data. The variables we explored reflected similar studies that have applied expectancy-value theory to engineering education research. For example, one study of first-year engineering students found that both expectancy factors (e.g.

self-efficacy) and value factors (e.g. identity) predicted academic achievement (in the form of first-year engineering GPA) and engineering career plans [30]. In a qualitative analysis of the career plans of engineering undergraduates, researchers found that participants' engineering identities varied widely, even within students retained in engineering majors, and that having a strong engineering identity was the strongest predictor of having engineering career plans [31].

In this analysis, we first found evidence for our hypothesized link between STEM high school preparation (in the form of diagnostic exam scores) and early self-efficacy in STEM classes in college. This finding supports both the expectancy-value framework and several decades of research on the impact of high school STEM preparation on college self-efficacy [32].

Second, STEM career aspirations and STEM identity appeared to be somewhat stable across three years, as early responses were moderate predictors of their respective values three years later. Individual characteristics such as interest and identity have been explored as both stable and unstable traits over one's life by various developmental researchers [14]. This finding is interesting in light of the research on the myriad challenges that STEM students face in college: despite their college experiences, students who enter college with relatively high STEM identity and career aspirations are likely to maintain these relatively high levels through the end of their sixth semester.

Next, once we controlled for initial values on each of these variables, the diagnostic exam showed marginal support for predicting sixth semester STEM identity. Further, the exam provided significant incremental predictive validity for STEM career aspirations after students' sixth semester of college. Although we did not find significant support for the impact of high school preparation on long-term STEM identity, our results support the model in finding that early STEM preparation had long-lasting ramifications for students' STEM career intentions.

Further, first semester self-efficacy did not provide incremental validity for predicting sixth semester career aspirations nor STEM identity. One explanation is that first semester self-efficacy and diagnostic exam score are already closely related, meaning that both were unnecessary to predict these outcomes. An alternate explanation is that students' first-semester self-efficacy impacted other factors during students' first three years in college that were more proximal to STEM identity and STEM career aspirations development that we were unable to capture in this study.

Despite this study's focus on primarily individual characteristics, social experiences clearly also impact college students' individual characteristics [33]. Consistent with our previous discussion on personal and social identities impacting STEM identity, we view students' three-year STEM identity as a reflection of both their evolving personal identity and their social identity that has been impacted by their experiences over their previous three years as a college student. Similarly, we view students' consequent career aspirations as the result of both their STEM identity and other social factors that may impact their career plans more directly. Both natural college experiences and planned interventions could theoretically impact students during their time in college in such a way as to alter their STEM self-efficacy, identity, and/or career aspirations, either positively or negatively [34].

Limitations

We were limited statistically in our ability to find significant relationships by our sample size, including conducting more detailed analysis of outcomes by specific STEM majors. However, the number of participants will increase as more cohorts enter the university, and we plan to evaluate more granular outcomes in the future. Because participants were juniors, we were also unable to capture students' eventual STEM career choices and instead were only able to assess students' career intentions at the end of their junior year. However, as it would seem unlikely that many students would change majors during their senior year, we expect a reasonably high correlation between intended and final major when students graduate.

Future Directions and Conclusion

This study explored objective high school preparation, psychological variables, and junior-year behavioral intentions of underprepared STEM students in the context of a well-established model of academic choices. We found that certain relationships were supported based on the predictions expected by the model. Overall, the fact that there was enough variance in these data to find significant relationships is notable, considering that this was a narrowly defined group of underprepared students in STEM (i.e. there is range restriction). To address the contribution of the social, college-level factors implied by the expectancy-value model to students' choices and behaviors, we plan to include measures of students' sense of belonging to the university in future studies. We will also examine students' STEM graduation rates and final GPAs, as well as their major-specific outcomes. We hope that the findings from these future studies and expectancy-value theory more broadly can ultimately be used to understand how both STEM students in general, and engineering students specifically, select, persist in, and ultimately choose to work in engineering fields.

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