Board 41: Development and Validation of the STEM Study Strategies Questionnaire for STEM College Students

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Abstract

In this research-based paper, we discuss the development of a measure of Rice University students' STEM study strategies and then explore the measure's correlation with several important psychological outcomes in a sample of underprepared first-year STEM students (*n*=94). STEM attrition remains a pressing concern nationally, particularly for students who took less rigorous STEM courses in high school, a population that disproportionally comprises underrepresented minorities. The authors developed an 11-item measure of STEM-specific study strategies, termed the STEM Study Strategies Questionnaire. We explored STEM-specific identity, self-efficacy, and career aspirations, as well as perceived utility of attaining a STEM degree, using a model based on Eccles and Wigfield's (2002) expectancy-value framework of achievement. An exploratory factor analysis found a four-factor solution to the newly developed scale: Group Work in STEM, Active STEM Learning, Interactions with STEM Professors, and STEM Exam Familiarity. The authors found significant moderate to strong correlations among all psychological variables, as well as with the Group Work and STEM Exam Familiarity factors. Next steps for this research are to develop further measure items to capture each of the four factors and to conduct confirmatory analyses on different samples of STEM students, both those who are relatively underprepared and appropriately prepared for college STEM coursework.

Introduction

STEM retention is an issue of national importance. Though there are undoubtedly systemic issues that pervade the STEM pipeline and hinder underrepresented groups in particular (and lead to higher attrition rates), weaker science and math preparation at the high school level also directly links to lower college STEM performance. High school STEM classes, particularly in lower-resourced schools, are designed to meet general state education standards rather than teaching STEM as a "scientific discipline" [1]. In particular, Black and Hispanic students are more likely to attend high schools that have fewer academic resources and advanced course options [2] and graduate from high school underprepared for college-level science and math [3]. Further, high-ability college students from less competitive high schools may have been unable to choose college-track courses, meaning that their courses may not have been challenging enough to engage in and develop in-depth STEM study skills [4]. When these students enter college, they may struggle to achieve high performance in their STEM classes for the first time.

More effective study strategies, which are behaviors that may result from students' beliefs and attitudes about themselves and STEM, may be needed to succeed in difficult college STEM coursework. Certain learning approaches consistently predict academic performance, including rehearsal of content, metacognitive strategies to evaluate self-learning, and self-regulation to persist in goal-directed learning behaviors [5]. However, many college students do not use the most effective study habits [6]. For example, Karpicke et al. [7] found that undergraduates studied most often by re-reading their textbooks and reviewing their class notes rather than actively testing their recall. Another study found that over half of college students studied for their exams in a single session [8], rather than spacing out their learning. Hora and Oleson [9] found in a qualitative study that almost half of STEM students reported “cramming” for their exams, meaning they began studying for an exam sometime from a few days before the exam to the night before it.

In terms of STEM-specific studying requirements, STEM as a discipline is distinct in many ways from other college majors. It involves scientific inquiry, problem-solving (often collaboratively), creativity, and a broad understanding of interdisciplinary concepts and how they relate to each other [10]. In particular, math is known to be more cognitively challenging than many other traditional academic subjects [11] and requires effective planning for success, not just consistent effort [12]. Researchers have argued that STEM education should equip students to interact with knowledge and solve complex problems, seek relevant information, and think critically [13]. Therefore, unique study strategies beyond general learning techniques derived from broader educational research might be effective for STEM students.

The findings on STEM study strategies suggest considerable variability in students’ study habits and their corresponding effectiveness, indicating that a study skills measure might be able to capture sufficient variability in STEM students’ learning behaviors in order to predict meaningful STEM outcomes.

To frame our conceptualization of the interplay among STEM study strategies and psychological constructs of interest, we use the well-known expectancy-value achievement model by Eccles and Wigfield [14]. In this model, students’ self-schemata (which we frame in this study as STEM identity) predicts their expectations of success (which we frame as students’ self-efficacy), which predicts their achievement-related choices (which we frame as STEM career aspirations as well as STEM study strategies), as do the subjective values students assign a task (which we frame as perceived STEM degree utility).

In this model, self-efficacy can be viewed as the extent to which students believe they are capable of learning and understanding academic topics, as well as successfully performing academic tasks to their own standards [15]. Career aspirations in STEM reflect the extent to which students believe a STEM degree will be necessary for their career goals. STEM identity is the extent to which people perceive themselves to have interest and ability in one or more STEM topics and have integrated this identity as part of their gender, race, and other cultural identities [16]. Finally, STEM utility is the extent to which students feel that a STEM degree will be helpful in helping them obtain their long-term career goals. See Figure 1 for our adapted model.

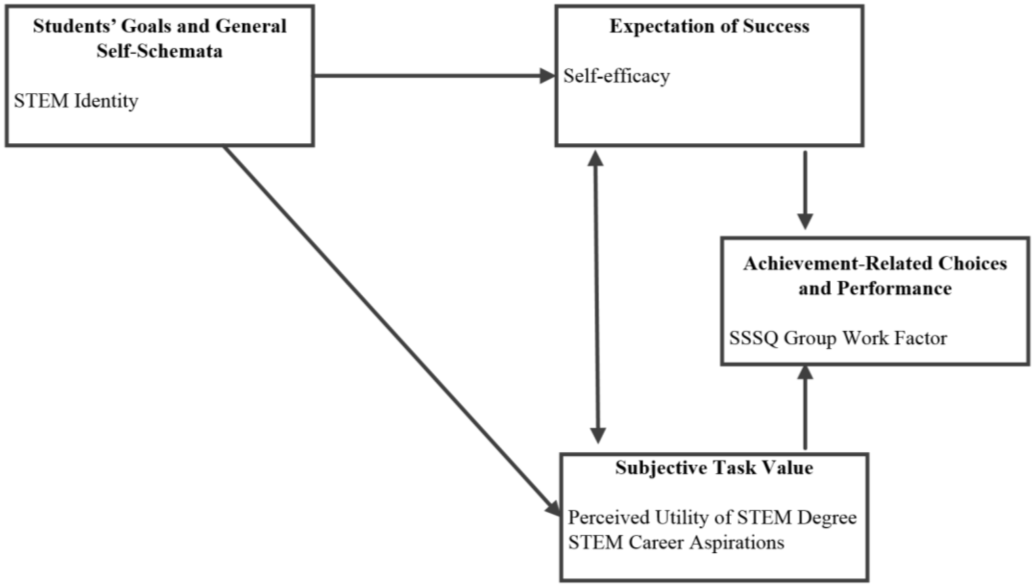

Figure 1. Adapted model based on Eccles and Wigfield's (2002) expectancy-value model of achievement.

Current Study

This study comprised a two-part process of 1) developing a measure of STEM study skills and 2) conducting an exploratory factor analysis (EFA) using a group of underprepared college STEM students as a sample.

Psychological Variables

Within this achievement framework, study strategies as achievement-related choices may be part of an interplay among student's self-schemata (i.e. STEM identity), their expectations of success (i.e. self-efficacy), their subjective task value (i.e. STEM degree utility) and their other achievement-related choices (i.e. STEM career aspirations).

STEM self-efficacy. We used the 8 self-efficacy items from the Motivated Strategies for Learning Questionnaire [17], altering the items to refer to STEM in particular, with options ranging from 1 (strongly disagree) to 7 (strongly agree). Items include "I'm certain I can understand the ideas taught in my STEM courses" and "I am sure I can do an excellent job on the problems and tasks assigned for my STEM courses." Cronbach's alpha was .92.

STEM career aspirations. This variable was assessed using 5 items from a Scientific Possible Selves measure [18] ranging from 1 (strongly disagree) to 5 (strongly agree). Items include "I expect to have a strong professional STEM career in the future" and "I have always hoped to have a STEM job one day." Cronbach's alpha was .80.

STEM identity. Items were based on the Academic Self-Description Questionnaire II [19] and a STEM intrinsic value scale [20], resulting in a 10-item measure ranging from 1 (strongly disagree) to 5 (strongly agree). Items include “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.” Cronbach’s alpha was .92.

Perceived utility of a STEM degree. STEM degree utility was measured with a 5-item scale [21] ranging from 1 (strongly disagree) to 5 (strongly agree). Items include “I need to do well in my STEM courses to be able to pursue my career goals” and “Getting a degree in a STEM discipline will be important for reaching my long term career goals.” Cronbach’s alpha was .93.

Stage 1: Developing the STEM Study Strategies Questionnaire (SSSQ)

Three subject matter experts (SMEs) at Rice University drew from their own experience personally instructing, advising, and in two cases designing new courses for college STEM students to rationally generate items they believed to be critical to success in STEM coursework. Key insights were provided by the literature on best studying practices, curricula of similar programs at analogous institutions, and students’ performance on individual exam questions in one gateway course. Two SMEs were STEM professors (one in mathematics and one in bioengineering) who contributed to the design of Rice’s STEM summer bridge program (the Rice Emerging Scholars Program), and the third was a director of Rice’s programming for less-prepared STEM students. The mathematics professor, who has worked at Rice University since 1988 and is past chair of the mathematics department, is also co-founder and faculty director of the university’s NSF-funded STEM four-year transition program. The bioengineering professor co-designed a first-year engineering class that emphasizes team learning and solving real-world problems. The program director has managed the STEM bridge program since its inception and provides academic advising to STEM students throughout the school year. All three SMEs have been actively involved with university efforts to improve the persistence and performance of undergraduate STEM students.

The items the SMEs designed reflected the strategies needed for STEM students to succeed in Rice’s traditional lower-level STEM sequence, which includes calculus, chemistry, physics, and engineering, and persist in lower-level STEM coursework that may be challenging and potentially discouraging to freshman students, especially those entering the university from weaker academic backgrounds.

This item generation process resulted in an 11-item measure using a 7-point Likert scale ranging from “Strongly Disagree” to “Strongly Agree” (the scale’s format was chosen to match the well-established Motivated Strategies for Learning Questionnaire’s 7-point scale, including its use of an agreement rather than a frequency scale) that we have termed the STEM Study Strategies Questionnaire (SSSQ). The items are included in Table 1.

Stage 2: Scale Administration and EFA

Participants

Participants (*n*=94) were first-year Rice STEM students in the 2016 or 2017 matriculating class who were identified as relatively underprepared for STEM coursework by university administrators based on students' high school records, including their STEM AP and IB credits, an internal rating system the university uses to evaluate the rigor of a high school's course offerings and quality of education, as well as low scores on a math and science diagnostic exam required of all matriculating STEM students at the university. However, these students, who were primarily underrepresented minorities, were selected for full admission into Rice, which is a highly selective university (the median Math SAT score for incoming STEM majors is approximately 770), meaning that their overall academic aptitude was strong (i.e. their high school GPAs were high, as were their standardized test scores).

For this study, STEM students were characterized as those originally matriculating in mathematics, engineering, or natural sciences. Social sciences and humanities majors were excluded, as were kinesiology majors, who do not have the same core major requirements as other STEM majors at the university.

Statistical methods

Exploratory factor analyses were conducted in SPSS. Based on Tinsley and Tinsley's [22] recommendation of 5-10 participants per item in a factor analysis, this sample of 94 students appears to be appropriate, as it represents approximately 8.5 students per item in this 11-item scale. Correlational and item analyses were also conducted in SPSS.

Procedure

During students' first two weeks of classes their first semester (Fall 2016 or Fall 2017), we administered the SSSQ as part of a larger questionnaire administered to STEM students via Qualtrics. The survey was optional, and students received $20 for completing the survey. The response rate was approximately 59%. We also captured four STEM psychological constructs of interest in this study: STEM identity, STEM self-efficacy, STEM career aspirations, and perceived utility of a STEM degree.

Results

Exploratory factor analysis

We ran an exploratory factor analysis on the administration of the SSSQ using principal factors analysis and varimax rotation. We found evidence for a four-factor solution using the criteria of an Eigenvalue greater than 1 and a review of the scree plot. See Table 1 for the results of this analysis.

Table 1. *Matrix of SSSQ Exploratory Factor Analysis*

Factors and Items		**1**	**2**	**3**	**4**
Factor 1: Group Work in STEM					
1	I talk to other students in my study group to ensure I understand major concepts.	**.889**	.045	.123	.033
2	I work on class assignments in groups.	**.784**	.284	.075	.061
3	I help others in my study group understand concepts and solve homework problems.	**.764**	-.123	.302	.143
Factor 2: Active STEM Learning Strategies					
4	I rework group assignments on my own to be sure I understand them.	.210	**.781**	-.017	.118
5	I rework homework problems before tests to make sure I can still do them.	.129	**.717**	-.036	.155
6	I complete any required reading before class to ensure I understand the major concepts.	-.171	**.566**	.214	.078
7	I have a structured plan to solve word problems on homework and tests.	.233	**.497**	.470	-.507
Factor 3: Interactions with STEM Professors					
8	I ask my instructors questions during or after class.	.149	-.080	**.844**	.177
9	I go over my completed tests and assignments with the instructor.	.201	.186	**.789**	.040
Factor 4: STEM Exam Familiarity					
10	I pick up my previous tests and rework problems I got wrong.	.088	.357	.371	**.733**
11	I take timed practice tests.	.429	.297	.071	**.587**

The SSSQ factors broadly referred to items representing 1) Group Work in STEM (items 1, 2, 3); 2) Active STEM Learning Strategies (items 4, 5, 6, 7); 3) Interactions with STEM Professors (items 8, 9); and 4) STEM Exam Familiarity (items 10, 11).

Loadings ranged from a low of .497 (item 7 in the Active STEM Learning Strategies Factor) to a high of .889 (item 1 in the Group Work in STEM factor). In the social sciences, items with loadings of .400 or higher, although representing low to moderate correlations in absolute terms, are generally accepted as appropriate to include within a single factor [23].

Internal consistency

Cronbach’s alpha for the sample was .84 for the Group Work factor, .67 for the Active STEM Learning Strategies factor, .74 for the Interactions with STEM Professors factor, and .63 for the STEM Exam Familiarity factor. Cronbach’s alpha for the full 11-item measure was .79.

Correlations

We examined correlations between the four scale factors and the psychological variables of interest. Though the SSSQ and MSLQ are on a 7-point scale and the other measures in this study are on a 5-point scale, correlation coefficients are independent of scale intervals, and standardization is not necessary when conducting intraindividual correlational analyses [24].

In this analysis, all correlations among the psychological variables were significant and moderate to large. The STEM Group Work Factor correlated moderately with all psychological constructs (ranging from r=.34 to r=.49), and the STEM Exam Familiarity factor had significant small to moderate correlations with all psychological constructs (ranging from r=.24 to r =.51). The Active STEM Learning Strategies factor had a small correlation with STEM Identity (r =.22), as did the Interactions with STEM Professors factor (r =.29).

The SSSQ composite scale had moderate correlations with all psychological variables (ranging from r=.34 to r=.44). Additionally, some of the scale factors correlated with each other. The Group Work factor correlated significantly with the other three factors, as did the STEM Exam Familiarity Factor. The Active STEM Learning Strategies factor also correlated with the Interactions with STEM Professors factor (r = .29). More data will be necessary in the future to further examine the psychometric properties of the SSSQ and its four subscales.

See Table 2 below for the full correlation matrix.

Table 2. *Correlation Matrix of STEM Psychological Constructs and SSSQ Factors*

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	STEM Identity	[.92]								
2	STEM Self-Efficacy	.59**	[.92]							
3	Perceived Utility of STEM Degree	.51**	.53**	[.93]						
4	STEM Career Aspirations	.60**	.60**	.70**	[.80]					
5	SSSQ Group Work	.48**	.49**	.36**	.37**	[.84]				
6	SSSQ Active STEM Learning Strategies	.22*	.09	.14	.18	.38**	[.67]			
7	SSSQ Interactions with Professors	.29**	.21	.15	.17	.28**	.29**	[.74]		
8	SSSQ Exam Familiarity	.24*	.24*	.37**	.38**	.51**	.43**	.45**	[.63]	
9	SSSQ Composite	.44**	.37**	.34**	.37**	.75^{**a}	.68^{**a}	.73^{**a}	.78^{**a}	[.79]

Note: Cronbach's alpha on diagonal in brackets; * p < .05, ** p < .01; ^{a} part-whole correlations

Discussion

We found a four-factor solution of the SSSQ using exploratory factor analysis. Our four factors were named Group Work in STEM, Active STEM Learning Strategies, Interactions with STEM Instructors, and Test Familiarity. These factors align well with several major learning theories.

Both the Group Work in STEM and STEM Exam Familiarity factors had small to moderate correlations with all other psychological variables. The Group Work factor may reflect cooperative learning theory, which addresses how students construct knowledge collectively. It is linked to the effectiveness of group work by increasing both learning and positive attitudes toward the subject being learned [25]. When completing group assignments, group members use each other as resources and depend on each other to achieve the highest success. The STEM Exam Familiarity factor may reflect findings on the effectiveness of practice testing and test familiarity, which have been linked to STEM performance. For example, Talley and Scherer [26] found that practice testing improved college students' exam performance on a complex neurology topic, and Dunlosky and colleagues [27] cite practice testing in general as one of the most effective study techniques. Both factors support the study's adapted model, in that these study strategies are the result of the other psychological variables in the model and therefore should correlate with them.

Conversely, the Active STEM Learning Strategies and Interactions with STEM Instructors factors both demonstrated small correlations with STEM identity and no significant relationships with the other psychological constructs. The Active STEM Learning factor, which includes items relevant to reworking assignments and planning how to solve difficult problems, may capture a combination of behavioral learning and information processing strategies. Behavioral learning theory emphasizes learning and retention acquired through exposure to and practice of material [28], and information processing theory describes how learners incorporate new knowledge into their existing knowledge set and increase their ability to retain new information [29]. The Interactions with STEM Instructors factor, which includes asking instructors questions and reviewing exams with instructors, may reflect a combination of behavioral learning and initiative-taking strategies. Students who exhibit initiative-taking behavior, such as asking questions in class and using professors as resources, have higher academic engagement in introductory STEM classes [30]. Behavioral learning theory has also linked direct instruction to retention [31], which may capture the actions of students who seek further explanations from their STEM instructors. Because both factors only correlated with the first stage of the expectancy-value model of achievement (the student's goals and self-schemata), the influences of these factors may impact identity formation, but they do not seem to persist into the later, more behaviorally-focused outcomes in the model.

Some of the items in the SSSQ may also be implicitly capturing distributed practice, in that the described behavior would be difficult to implement immediately before taking an exam (for example, asking an instructor questions before or after class, or consistently completing required reading before class). "Distributed practice," or spreading out the studying process over a certain time period, has been consistently linked to better long-term recall [32].

Correlations among all psychological constructs were moderate to large, and the composite SSSQ scale demonstrated moderate correlations with all psychological constructs. Overall, our findings demonstrate that STEM-specific study behaviors may be assessed on a new scale and load onto distinct factors that correlate with psychological variables relevant to STEM achievement.

There are several notable limitations to this study. First, the type of sample is a limitation. This is a targeted sample of high-achieving but academically underprepared STEM students. This measure would need to be validated on different samples to determine whether scale correlations change for different groups. Whether effective strategies differ by STEM class (an engineering versus calculus course, for instance) is also an area for future research. Further, as with all correlational studies, we cannot assume causal relationships between study strategies and STEM psychological outcomes.

Future Directions and Conclusion

This study is a first step in the development of a study skills assessment. Our next steps include conducting a confirmatory factor analysis on a separate sample of STEM students, as well as generating items to ensure that each factor captures at least the generally recommended three items per subscale [33] and refining scale items to further increase the reliability of the four factors. We also plan to explore whether there are differences in the most effective learning strategies for different types of STEM classes, as well as for classes that emphasize STEM technical skills.

As the students in this study proceed into their second and third years at the university, we also plan to explore the SSSQ's predictive validity for objective STEM outcomes, including STEM retention and STEM GPA. Group work, for example, may increase students' persistence in STEM through both exposure to STEM topics and exposure to students who are also persisting as STEM majors. Additionally, group studying may increase individual learning, which may in turn increase STEM grades. Finally, we will also determine whether the scale has predictive validity over longer time periods on the psychological variables assessed in this study.

We are optimistic about the potential to develop a reliable measure of STEM study strategies, as well as explore whether intervening to change students' study behaviors can improve important STEM outcomes.

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