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# Success in the STEM Curricula

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## Abstract

The importance of the STEM (Science, Technology, Engineering and Mathematics) professions to America's ability to advance its quality of life have long been a matter of discussion on a national level. The rewards of study in these areas are as evident to those who teach it, as they are, often, difficult for students to appreciate. This article seeks to delineate evidence-based factors relating to student success in STEM at the post-secondary level, focusing especially on secondary school preparation and competence in mathematics and other STEM areas. The article concludes with suggestions for curricular and pedagogical approaches to address some of these issues.

### Dr. Narayanan

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## Introduction

Post-secondary pedagogical theory embraces the notion that how we teach is as important as what we teach. Incoming students have a wide variety of abilities. This presents a dilemma in terms of teaching. It is not just a question of multi-media versus traditional lecture approaches; it is an issue of how students who may be insufficiently prepared to handle college-level work can be successful as they begin their studies. We want to find a way to supplement their basic fund of knowledge and skills without diverting time from course material. We have a responsibility to provide assistance to students who are underprepared for college.

How we came to this problematic situation involves a confluence of multiple factors. The ability to resolve these issues requires an evidence-based approach. In general, we wish to reverse the trend of fewer students pursuing STEM majors in the U.S., as well as of students who switch their majors from STEM to other programs. STEM is a very attractive disciplinary field; however, it is a field in which retention rates are decreasing. We propose to review some of the evidence regarding problems that lead to failing students. We present a brief overview of articles and other publications that have looked at student preparation, teaching methodologies, and other facets of the metaconceptual framework of this problem. We will then propose suggestions for further study, to spur further inquiry into practical methodologies to address these issues.

### Dr. Sturtz

Dr. Sturtz is a veterinarian who teaches in a veterinary technology/pre-veterinary medicine undergraduate program at Mercy College. She graduated in 2004 with a degree in veterinary medicine from the University of Georgia. She is highly interested in feline internal medicine.

## The math dilemma

STEM disciplines have a number of emphases in common, including conceptual and computational skills. In professions as diverse as nursing, civil engineering, and chemistry, the ability to manipulate figures, and draw conclusions from numerical data is essential. However, the ability to demonstrate mastery of these skills in college-level courses eludes many students. It would seem intuitive that students intending to pursue a STEM major have good skills in mathematics and natural sciences. And yet, undergraduate instructors often lament the lack of these skills in incoming STEM students. Stotsky and Wurman (2009) noted, “According to a 2008 report by the CUNY Council of Math Chairs, 90% of 200 City University of New York students tested could not solve a simple algebra problem in their first class at a four-year college” (p. 24). Data from the U. S. Department of Education suggested that students who major in STEM areas are more likely to finish a degree in these areas if they took trigonometry, precalculus, or calculus in high school, had a high school average of B or better, scored in the top quartile on college entrance examinations, and had planned on graduate study. Other results indicated that student success in pre-calculus courses was a good indicator of success in college calculus (Stigler, Givvin, & Thompson, 2010).

A survey conducted for the National Center for Education Statistics indicated that almost half of students who leave the STEM majors do so with GPAs at least 0.5 points below their non-STEM counterparts. This correlates with work done by Stinebrickner and Stinebrickner (2011), who found that students move away from science and mathematics majors “after realizing that their grade performance will be substantially lower than expected” (p. 25).

Not surprisingly, it seems that students do not succeed in mathematics and science in college unless they have been well prepared in mathematics and science beforehand. It also seems that students who cannot achieve the good grades they are expecting are often going to leave their major for a non-STEM academic pathway.

Hassi, Kogan, and Laursen (2011) examined Inquiry-Based Learning (IRB) in undergraduate mathematics education. This teaching method involves allowing students to use a question-and-answer method of searching for answers to specific mathematical problems. The student is encouraged to find a method for solving the problem first, then to evaluate it and compare it to other methods. This type of teaching seems to have positive benefit, particularly for low-achieving students. In Hassi, Kogan, and Laursen (2011) study, active learning and discussion led to increased student interest, cognitive gains, and perseverance. Data used included student surveys and transcripts. Further, according to Ganem (2009), trying to teach a student how to solve complicated problems is not the same as teaching rigorous problem-solving skills. The point is not to teach the student how to solve a calculus problem, so much as to give the student the baseline mathematical skills to understand why the problem needs to be solved in a certain way (Ganem, 2009).

A study conducted across seven universities in the United Kingdom demonstrated poorer than expected mathematical skills in bioscience undergraduates, specifically in solving contextualized word problems.

These errors and misconceptions were similar to those made by high school students (Tariq, 2008).

Insufficient mathematical background leading to a high failure rate in first-year science subjects has been observed across many universities in the United Kingdom, Ireland, Australia, and the United States. Upon comparing student performance in college-level and secondary school mathematics courses, and scores on the standardized national college entrance examination, secondary school mathematical background was found to be the best predictor of success in college level science (Rylands & Coady, 2009). Culpepper et al found that taking calculus and trigonometry during high school is correlated with better performance in general biology and algebra while in college (Culpepper et al., 2002).

Jackman et al. (2001) conducted a survey among engineering students in the United Kingdom to better understand their attitude towards mathematics. Important influences included academic experience before entering college, specific curriculum while in college, and college workload. Conceptual difficulties with high-school level mathematics and erroneous techniques of applying mathematical concepts were found to influence performance in college mathematics. Further, an applicant’s qualifications for entering college and his/her attitude toward mathematics appear to be related (Jackman, Goldfinch, & Searl, 2001).

Researchers in the United Kingdom have developed a powerful technique called the “Analytical Hierarchy Process” that quantifies mathematical skills. This technique was used during a pilot study on high school seniors, and helped identify students who were underprepared for college with regard to their mathematical abilities (Warwick, 2007). Hu et al. (2012) have shown that afterschool programs are quite effective in improving student performance, and Pokorny et al. (2005) have made an attempt to understand highly variable student performance in an introductory statistics course. They recommended that any modifications to instructional delivery or enforcement of highly independent learning should be based on individual student development.

Some studies have been done to assess mathematical computation deficits observed among STEM majors. Stigler, Givvin, and Thompson (2010), reported that “conceptual atrophy” among students causes them to forget most of the mathematical computations they have been taught during high school. This occurred because students were not taught to apply these procedures across a broad range of problems. Since mathematical concepts are closely related to calculation, these students have difficulty with mathematical problem-solving as well. This study suggests that these students can be re-directed into applying mathematical concepts to specific problem solving by way of reasoning-based teaching.

Under-preparedness in computational mathematical skills has also been observed among nursing students. This is a cause of great concern since these skills are crucial for, among other things, accurate dosage calculations (Brown, 2002).

## High school performance as a predictor

High school competency and training appear to heavily influence student performance in college. They also seem to have a definitive role in shaping career paths that students pursue. Several research groups have found that average high school GPA (HSGPA) was the best predictor of college success (Santee & Garavalia, 2006; Wolfe & Johnson, 1995; Chisholm, Cobb, & Kotzan, 1995). Geiser et al. (2007), observed that the correlation of HSGPA with college grades seemed to be greater as students advanced through their college years. Also, taking challenging college-level courses while in high school appears to help students excel in college (Alleyne, 2013; Clark, 2007). Competencies in certain subjects seem to have a greater influence than others. Proficiency in high school Algebra II helped students perform better in college-level mathematics. The same was true for chemistry, biology and physics. Further, courses taught in depth, those that gave rigorous mathematical training and those that involved a laboratory component helped students succeed in college science (Ackerman, Kanfer, & Beier, 2013).

Students in high school who were prepared for chemistry laboratories by discussing principles and concepts ahead of time performed better in college than those prepared by stressing specific laboratory procedures. These findings could be useful while designing high-school curricula (Tai, Sadler, & Loehr, 2005; Snyder, Shorey, Cheavens, Pulvers, Adams, & Wiklund, 2002). One study found that advanced placement courses had little or no influence on college success (Ackerman, Kanfer, & Beier, 2013). Note that this differs from the Georgia study (Alleyne, 2013), which found that taking college-level courses in high school would be of benefit. Researchers evaluating student performance in mathematics and English at the University of South Africa found no relation between high school and college performance

(Marnewick, 2011). In contrast, at the State University of New York, high school achievement emerged as the strongest predictor of college success for men, but not for women (Wesley, 1994).

## Personal and psychological factors

Study habits, stress management, self-motivation, and healthy lifestyle would seem to be important to any student. There is sufficient evidence to suggest that this is indeed true in the STEM majors as well.

Success, in the form of good grades, in the early years of college does appear to heavily influence retention rates. As noted earlier, data gathered by Stinebrickner & Stinebrickner (2011) indicated that although many students are open to majoring in mathematics or science upon entering college, many of them eventually switch majors due to poor grades scored in early coursework. Student feedback indicated that although they were willing to work hard, they were unable to compensate for their lack of ability in mathematics and science.

Analysis of psychological factors as a valid predictor of college performance has been done at several institutions. Robbins et al. (2004) found that academic success and motivation were stronger predictors than factors like socio-economic status and standardized test scores. In another recent study, among six psychological factors that were analyzed, academic efficiency due to individual effort and organized study skills was found to influence college success to a greater extent (Krumrei-Mancuso et al., 2013). However, social and emotional factors like alcoholism and stress also appear to play a major role, though, parental educational level had little or no bearing on college success (Clark, 2007).

A study conducted over four years in the Astrophysics department of the Harvard-Smithsonian Center evaluated factors such as teaching style and “curricular practices” in high school. This study found that certain practices in high school such as class projects, use of demonstrations as a teaching technique, and prior preparation for laboratories, positively affected student performance in college (Tai, Sadler, & Mintzes, 2006).

Advanced placement (AP) exam scores, student personality, motivation, and positive self-image were found to be more predictive than standardized test scores and HSGPA (Santee, & Garavalia, 2006; Ackerman, Kanfer, & Beier, 2013).

Gender-related factors have also been investigated. A positive self-concept seemed to affect females more than males. Skills like organization and mastery had a greater influence on males. Among non-traditional undergraduates at a mostly-Hispanic institution, self-motivation and conscientiousness were found to greatly influence freshman success (Kaufman, Agars, Lopez-Wagner, 2008). Furthermore, physical fitness, effective time-management, psychological health, good study habits, and strong reading and writing skills were also key factors. Wolfe et al. (1995) found self-control to take precedence over SAT scores, and Schutte and Malouff (2002), found that emotional intelligence and maturity greatly influenced college performance, especially in the first two years.

## Peer tutoring

Peer tutoring, while not a new concept, has received renewed attention. A report published by the National Center for Education Statistics (2011), using pharmacy students as a model, determined that positive outcomes might arise through peer tutoring. However, enough of the work had “numerous methodological flaws and limited descriptions of the programs and participants,” that the authors felt this work might not provide a rigorous platform for confirming that peer tutoring was of value.

## Support Services

The issue of establishing successful support services is quite complex, in that it is difficult to obtain clear scientific evidence that these services are effective. In a report to the U. S. Department of Education on student support services, published in 2010, the point was made that support services received by students in the freshman year seemed to be associated with “moderate increases” in retention and eventual graduation with a degree. It was also noted, though, that while there was no significant effect on the number of students transferring from two-year to four-year schools, neither was there a significant difference in “some of the key measures” in the statistical analysis. The study notes, “The alternative outcomes if students had not participated in SSS [student support services] could only be estimated through statistical models” (Chaney, 2010).

## Discussion

In this article, we have reviewed the issue of how students are prepared for STEM education at the college level. It seems that there is enough evidence to conclude that there is an ongoing struggle to retain students within STEM-based college programs, and that this problem is linked to high school preparation, higher order mathematical skills, and a number of individual student characteristics.

The next obvious question is: “How and where do we start to remediate this?”

Upon exploring predictive validity of several factors, it seems that high school preparation plays a major role in influencing college success. Many studies conclude that high-school curricula rich in natural science and mathematics courses, laboratories that stimulate critical thinking, and opportunities for taking advanced college-level science and mathematics courses are beneficial to students.

Competency in mathematics is the other key factor. Students who gain proficiency in mathematics during high school perform very well in college level science courses (Stinebrickner & Stinebrickner, 2011; Schauner, Hardinger, Graham, & Garavalia, 2013). Below, we propose some strategies that could make post-secondary mathematics curricula more applicable to STEM majors:

1. Restructuring courses to include more word problems that involve concept application, in addition to formulaic substitution and factual memorization.
2. Including courses that stimulate comparative reasoning skills.
3. Setting classes with conceptual focus as prerequisites to advanced calculus, trigonometry and algebra.

Along these lines, Middle Tennessee State University restructured curricula for several of its developmental courses. Results of the pilot year of this study were evaluated for two mathematics courses. Student performance reportedly improved, and success in preparatory courses allowed for fewer pre-requisites, versatile delivery, cost-effectiveness, and a technology-rich curriculum (Ballard & Johnson, 2004).

While personal factors (e.g., study habits, physical and emotional health) are important, high school success and mathematics performance are a major influence on how a student performs in college. This is reflected in grades obtained during freshman year (Stinebrickner & Stinebrickner, 2011; Schauner et al., 2013). We recommend restructuring STEM curricula by including the following mandatory courses:

1. Introductory Mathematics, which strengthens basic algebra and computational skills.
2. Introductory Science, which addresses basic problem solving (encompassing all science subjects) involving application and comparative reasoning.
3. A science-writing comprehension course that strengthens precise as well as descriptive science writing.
4. Depending on the curriculum, having either biology or chemistry as a pre-requisite to the other is preferable to having students take them as co-requisites, allowing for a stepwise increase in the ability to handle higher-order concepts.

We also suggest the following next steps to evaluate our proposed approaches:

1. Having a pre-test which specifically assesses mathematical, writing, and science problem-solving skills necessary for the STEM major in question.
2. Early intervention strategies like tutoring, peer-assessment, faculty advising, and continuous

monitoring for students identified by the pre-test as being at risk.

3. Having a post-test with the same testing modules as the pre-test described above to measure progress.
4. Modifying intervention strategies on an as need basis, based on individual performance.
5. Repeating post-tests on a regular basis until measurable progress is achieved.
6. Consolidating data obtained for future evaluation, assessment, and curriculum revisions.

Getting an undergraduate STEM-based degree is very demanding, and can be overwhelming to some. We have presented some recommendations and intervention strategies that we believe would highly benefit educators, college admission committees, and students, and pave the way for a new generation of STEM professionals.

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