Tackling the STEM Recruitment & Retention Challenges at a Flagship, Research Institution With an Evidence-Driven, Innovative Hybrid Course

Sheila Tabanli, Rutgers University-New Brunswick, United States

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Abstract

The challenges of recruitment and retention in STEM did not start with the COVID-19 pandemic; however, these challenges still affect the workforce needs of our world. Historically marginalized students in STEM fields are disproportionally affected by these ongoing challenges that further causes diversity & inclusion issues in the workforce. An innovative hybrid course grounded on research from cognitive science and social emotional learning was designed to address these educational challenges at a flagship, large research university in New Jersey, USA. This interdisciplinary course framework is aimed to address (1) the research-to-practice gap between cognitive science research and classroom practices, (2) the perception gap between the instructors and students (expert-to-novice perception gap), (3) the conceptual and procedural gaps in students' learning and studying. Furthermore, authentically designed instructional resources and assessments address students' math mindsets and anxieties by fostering students' sense of belonging in a discipline that disproportionally affects marginalized groups. We hope our work will serve as a driving force to promote interdisciplinary discourse and improved awareness in an area that needs multifaceted approaches to a core issue of our time, namely the ongoing STEM recruitment and retention challenges.

Keywords: STEM Education, Recruitment and Retention, Interdisciplinary Curriculum Design, Cognitive Science, Social Emotional Learning

Introduction

The discipline of Mathematics is considered a gateway to STEM majors, however, due to several factors negatively contributing to students' perceptions, studying, and performances in introductory undergraduate math courses it is becoming a gatekeeper to STEM. This outcome negatively impacts the needs of our technology-driven society in the forms of STEM recruitment, retention, and workforce challenges. In the context of our paper, we define research to practice (R2P) gap as the research on human learning not being integrated into the math classrooms. In an era where students are digital natives and due to the dual nature of our complex attention system which makes us capable of focusing but open to distractions (Lang, 2020) classrooms with the traditional, teacher-centered instructional practices are not meeting the needs of these highly interactive learners. The curse of knowledge (Newton, 1990) states that experts do not tend to see the challenges within their discipline from the novice's perspective. In other words, once a novice levels up to an expert status this tends to contaminate the ability of the expert to see the same facts from the novice's less informed perspective. In some literature, this is referred to as the hindsight bias (Bernstein et al., 2004), the curse of expertise (Hinds, 1999), or the knew-it-all-along effect (Fischhoff, 1977). The instructors' expert attitudes may introduce an additional barrier to students' math learning in the form of expert-to-novice perspective gap. Furthermore, the widely accepted negative social norms such as the myth of a math brain combined with a recently acquired pandemic learning gap adds more gaps to the existing math achievement gap in the form of conceptual and procedural gaps. The discipline of mathematics demands conceptual mastery and procedural fluency for effective math learning. Redmond-Sanogo et al. (2016) suggests that obstacles keeping students from achieving STEM degrees may include uninspiring introductory courses, lack of adequate preparation in the content of mathematics, and academically or culturally uninviting environment to underrepresented populations.

Packer (2022) asserted that several professional organizations such as MAA, NSF, NCTM have repeatedly called for fundamental changes for students' mathematical experiences. These changes are aimed to offer students deep engagement with mathematical ideas and productive struggle in solving novel problems, learning goals and trajectories informed by mathematics education research and not simply a reproduction of instructors' experiences as students, and a focus on coherence across lessons and units (and courses) so students see how key "big ideas" extend across topics. Our interpretation of the second point in this assertion is, an instructor such as the author of this paper who attended undergraduate studies in a different country in a different decade needs to be mindful of the current, relevant mathematics education research to improve students' learning experiences. The alternative to this approach is to rely on the way the content was taught in her native country in the late 1900s.

Covid-19 pandemic brought additional challenges to everyday life including the education field. (Sparks, 2022) stated that, after the pandemic, math achievement fell across every percentile, even for the highest performers, the latest graduating class of 2022 had historically low scores on college placement tests. One robust way to combat these challenges is to bring evidence-based teaching practices to our classrooms. Cognitive science research provides many insights into potential ways to improve teaching and learning in schools, but those insights infrequently make their way into classrooms (The National Academies of Sciences, Engineering, and Medicine, 2018). Students who know about the different kinds of strategies for learning, thinking, and problem solving will be more likely to use them (Pintrich, 2002).

In this paper, we describe an innovative curriculum with particular emphasis on the cognitive science principles and social emotional learning techniques that facilitate students' math learning. The course design itself is grounded on Fink's Taxonomy of Significant Learning (Fink, 2003) that incorporates cognitive and affective domains of learning. The curriculum is intentionally designed in a way to include a wide range of evidence-based practices and frequent no- to low-stakes assessments to further address widely accepted negative social norms and misconceptions about math in general. This innovative course development sought to (1) cultivate a stimulating first-year student experience and classroom culture grounded on the empirical and theoretical knowledge from the science of learning, (2) offer an inviting learning environment with frequent assessments nurturing the sense of belonging through social emotional learning principles.

Development of Pilot Course

The initial course development was started by the author during the earlier stages of the pandemic after observing ineffective study techniques in her Introductory Calculus course. Historically, the introductory undergraduate calculus courses have high DFW rates at several higher ed institutions. After meetings with the university leadership at the school and department level, the course was initially offered as a pilot program in fully synchronous 2-credit virtual format during Winter 2022 semester over a three-week period. The projected outcome of our curriculum design efforts is to improve first-year student learning experiences such as students' sense of belonging and math learning outcomes.

The curriculum has three modules designed in Canvas Learning Management System as seen in Figure 1 below. The first module is aimed to improve the cognitive domain, the second module is targeted as an "intervention" for the affective domain. The third module is a combination of both cognitive and the affective domains by reflecting and implementing the strategies learned in the previous two domains.

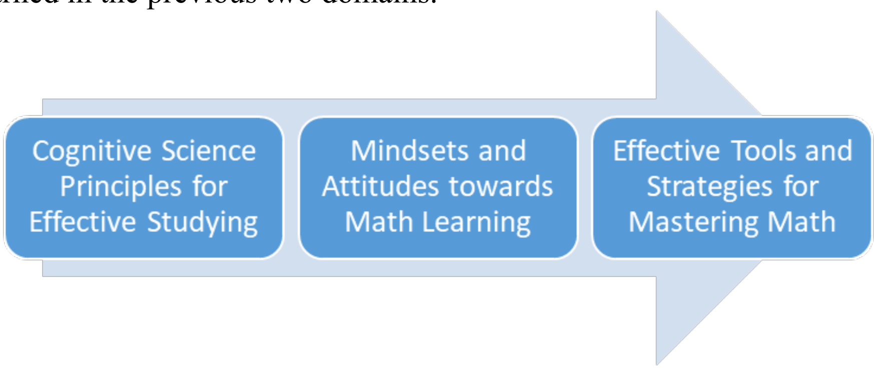

Figure 1: The Pilot Course Curriculum

Intentionally Addressing the Gaps in Students' Math Learning and Performance by using Engaging, Student-Relevant Assignments

In the pilot course curriculum, every module has a core assignment that offers some creativity and flexibility for students. For example, the first module's core assignment is for students to critically read (Dunlosky et al., 2013) and learn about the low, moderate, and high utility learning techniques as demonstrated by several experiments and research articles. Students are invited to use metacognition to reflect on their current learning strategies, then refer to the article to find out which of their current strategies are considered low utility, which means low impactful. (Dunlosky et al., 2013) explains each of the learning technique by describing the content and the rationale behind why it is classified as a low/moderate/high utility strategy, providing empirical evidence for different student characteristics, and the issues in implementation for educational setting concluded with an overall assessment of the technique. The students are tasked to become familiar with all techniques, however, they are given flexibility to pick only one technique to teach it via a video recording. The instructor provides a template explaining the distributed practice technique for students to see the expected outcome for this core assignment. Table 1 below includes the description of the learning techniques as reprinted from (Dunlosky et al., 2013).

Table 1. Learning Techniques

Technique	Description
1. Elaborative interrogation	Generating an explanation for why an explicitly stated fact or concept is true
2. Self-explanation	Explaining how new information is related to known information, or explaining steps taken during problem solving
3. Summarization	Writing summaries (of various lengths) of to-be-learned texts
4. Highlighting/underlining	Marking potentially important portions of to-be-learned materials while reading
5. Keyword mnemonic	Using keywords and mental imagery to associate verbal materials
6. Imagery for text	Attempting to form mental images of text materials while reading or listening
7. Rereading	Restudying text material again after an initial reading
8. Practice testing	Self-testing or taking practice tests over to-be-learned material
9. Distributed practice	Implementing a schedule of practice that spreads out study activities over time
10. Interleaved practice	Implementing a schedule of practice that mixes different kinds of problems, or a schedule of study that mixes different kinds of material, within a single study session

Note. Reprinted from "Improving Students' Learning With Effective Learning Techniques: Promising Directions From Cognitive and Educational Psychology" by Dunlosky et al., 2013, *Psychol Sci Public Interest. Jan;14(1):*4-58.

Students are invited to use the evidence-based learning strategy, generation effect, to create knowledge based on their readings. (Kelley et al., 2019) demonstrated that the generation effect, which occurs when individuals remember materials, they have generated better than materials by others, along with retrieval practice improved student exam performance. For this core assignment, students are tasked to create a short video teaching their chosen technique over a document (such as a Microsoft PowerPoint file) they also create in order to teach it to an audience. Students can either choose a moderate or high utility learning technique based on the reading. In addition to teaching this evidence-based technique, students are expected to include an attainable weekly study schedule and how they plan to incorporate this one technique in their studies. The authentically created videos by students also improve students' presentation and technology skills. Students are given opportunities to implement the two moderate-utility techniques, elaborative interrogation and the self-explanation, in their assignment submissions. Students are expected to critically respond to the why and how questions of elaborative interrogation and explain the technique in their own words.

To understand students' attitudes towards the discipline of mathematics, the core assignment of the second module is a case study of the research demonstrated in (Code et al., 2006). In order to support mathematical novices' transition to more expert-like perceptions of mathematics we need to first characterize students' perceptions of mathematics, then help students to develop a productive disposition for mathematics. (Code et al., 2006) proposed to address this need by the meticulous creation and verification of the MAPS (The Mathematics Attitudes and Perceptions Survey). In this core assignment, students are tasked to take this survey then rate themselves based on the provided rubric (Code et al., 2006). The outcome of the survey reveals how likely the students' attitudes to experts' attitudes in the field of mathematics are. For example: a student who scores low on the growth mindset sub-category of MAPS will benefit from taking the mindset intervention (Dweck, 2008) later in the module. A follow-up discussion board was created in CANVAS by mapping each of the sub-categories of the MAPS to students where students utilized the generation effect to create a video of their further analysis of the sub-scale. In order to empower students and improve their sense of belonging, students are also tasked to relate this sub-category to their life experiences in math classes. For example, after going through growth mindset induction exercise (Dweck, 2008) in this course, they share how would they react to the previous experience differently. This assignment enables students to implement compare-contrast methodology for fixed and growth mindset personalities. The action verbs of compare-contrast are considered a moderate-high level of thinking (Blooms, 1956). By addressing students' (mis)perceptions of their math abilities and clarifying the myth of a math brain through assignments we aim to improve students' sense of belonging and address their social-emotional learning needs in a safe learning environment.

The third module combines both affective domain and the cognitive domain principles that are learned in the first two modules. The core assignment for this module is to take a math test by using evidence-based strategies, then to receive grading feedback from the instructor and to use metacognitive skills to re-attempt the problems in order to fix the previous mistakes. The expected outcome of this assignment is for students are threefold: (1) to study by using the moderate-high utility cognitive-science based learning techniques (Dunlosky et al., 2013), (2) to approach math problems with a growth mindset and a better perception towards their math abilities (Dweck, 2008; Code et al., 2006), (3) to incorporate the principles of metacognitive thinking into mathematical practices. The overall benefit of this threefold implementation cycle is to reduce the conceptual and procedural gaps in students' learning and studying.

Future Directions and Conclusion

Students are encouraged to use evidence-based strategies such as generation effect in completing the assignments. Creating a repository of student products would help the future students to view sample assignments to guide them in the process. This is a feasible task for the author since as a part of the end-of-semester celebratory event students are asked if they give permission for their names and work to be shared with other students for educational purposes. The author can easily select the sample work for the students who give such permissions.

Although the core assignment for the first module requires students to identify the effective study techniques, a follow up assignment would enable distributed practice and retrieval practice opportunities for students to combat their forgetting curve. A viable alternative is to have students pick a different moderate-high utility learning technique to implement in the following weeks of the semester based on the already submitted study schedule. This could be facilitated as a discussion board activity. This way students are encouraged to share their best practices and what worked or did not work for them to make their experiences more relatable to their peers, in order to foster a community of learners. Furthermore, this will improve individual accountability.

Case-based learning has a strong history of effective application in medical, law, and business schools, and is increasingly used within undergraduate education (Herreid, 1994).

Williams (2005) describes the several advantages of case-based learning such as improving student motivation to learn, encouraging self-reflection, fostering scientific inquiry, and integrating knowledge and practice. In addition to the MAPS survey result discussion and students representing themselves as a character in a case study, due to the aforementioned advantages of case-based learning the author plans to construct more case studies for students to discuss in groups to enhance active participation, teamworking, and presentation skills which are skills desired by the employers.

The alternative to incorporating evidence-based strategies to classrooms is not to incorporate these techniques and not to teach them to the students. Although domain experts may have a perceptive of novices knowing how to learn in their domains, many novices (students) may arrive at post-secondary institutions without actually knowing how to learn effectively. This may be due to the fact that students may not have ever learned it before. Our goal in this paper is to provide a curriculum framework, similar to the concept of a co-req, to be paired up with STEM courses for first-year undergraduate classes.

Recommendations

To bridge research to practice; the author completed an extensive literature review, developed an innovative course curriculum to create an authentic Canvas course website with three modules. In this novel course, information and assignments were presented in diverse formats such as videos, PlayPostIt quizzes, discussion boards, peer reviews of presentations, student-generated videos, math problem solving sessions. In a higher educational setting, bringing the research on human learning to the practice of human teaching is a much-needed instructional strategy specifically in the discipline of mathematics where U.S. students underperform their peers on international assessments such as Trends in International Mathematics and Science Study (Mullis et al., 2020). We conclude this instructional paper with key recommendations as follows.

In a discipline where students universally struggle with numerous challenges that creates culturally acceptable social norms such as some people are born with a math brain, boys are better than the girls in math, it is crucial for experts in their respective disciplines of mathematics education, pure math, and applied math to collaborate in order to offer improved learning experiences to students. The author asserts that intentionally creating such a strong collaboration coupled with empathy-filled classrooms to novices' perceptions of math, will create research-driven, student-centered practices for all. By promoting interdisciplinary discourse and innovative curriculum design ideas, we can create multifaceted solutions to an evolving problem, namely STEM recruitment and retention. This proposed initiative has the potential to address the persistent STEM recruitment and retention challenges, as well as the factors that disproportionally affect marginalized groups in STEM.

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