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STEM Graduation Trends and Educational Reforms: Analyzing Factors and Enhancing Support

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ABSTRACT

This article explores the complex dynamics of STEM education in the U.S., focusing on the attrition rates of students pursuing degrees in science, technology, engineering, and mathematics. Despite a significant increase in the number of STEM degrees awarded, challenges in student retention and global competitiveness remain. The analysis delves into the reasons behind high attrition rates, including the difficulty of introductory courses, lack of support and mentorship, and insufficient high school preparation. To address these challenges, this article highlights the effectiveness of innovative teaching methodologies such as peer instruction, project-based learning, retrieval practice, and active learning strategies. These approaches have shown promise in enhancing student engagement, comprehension, and retention, thereby improving STEM educational outcomes. Furthermore, the article underscores the need for systemic educational reforms and robust support systems to foster an inclusive and equitable learning environment. By adopting evidence-based teaching practices and addressing systemic barriers, educational institutions can better prepare students for the demands of STEM careers and contribute to maintaining the United States's leadership in global scientific and technological innovation. This comprehensive examination serves as a call *for stakeholders in academia, policy, and industry to collaborate in creating a supportive and effective STEM education framework.*

Keywords*:* Applied Research, Classroom response systems, Education reform, Inclusive learning environments, Retrieval practices, STEM education, Working memory

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INTRODUCTION

Approximately thirty-eight percent of students who started with a STEM major such as physics or mathematics did not graduate with a degree in their declared STEM discipline (Whitcomb & Singh, 2021). However, the number of STEM degrees awarded in the U.S. has been increasing over the past few years. For example, in the 2020-2021 academic year, U.S. institutions awarded approximately 437,302 bachelor's degrees in STEM fields, representing a significant portion of total degrees awarded (National Center for Educational Statistics, 2024). This trend suggests that more students are choosing to pursue and complete degrees in STEM fields.

This increase is part of a broader trend of increasing interest and enrollment in STEM fields. The growth in STEM degrees is consistent across various levels of higher education, including master's and doctoral degrees. For example, in the 2020-2021 academic year, approximately 146,573 master's degrees in STEM fields were awarded (National Center for Educational Statistics, 2024).

Impact on innovation

This upward trend reflects various efforts and initiatives to promote STEM education, addressing both educational policies and the labor market demand for STEM skills. Despite this growth, challenges remain in terms of diversity within STEM fields, with the underrepresentation of certain demographic groups, such as women and minorities in some STEM occupations (National Academies of Sciences, Medicine, and Engineering, 2019).

Despite the increase in STEM graduates, the U.S. has experienced challenges in maintaining its leadership in global scientific and technological innovation. For instance, the share of research articles published by U.S. scientists in leading journals has declined from 40% in the 1990s to approximately 16% by 2020. Additionally, in 2022, China produced 27.3% of the world's scientific and engineering articles, while the U.S. accounted for 13.7% (U.S. National Science Foundation, 2022). This indicates that while the number of STEM graduates is rising, the global competition in research and innovation has intensified. Regarding patents, over half of U.S. patents were awarded to foreign companies by 2021, highlighting the increasing international competition and collaboration in technological advancements.

In summary, while the number of STEM degrees awarded in the U.S. is growing, the country's share of global scientific publications and patents has declined, reflecting broader international trends and competition in innovation. According to the U.S. Bureau of Labor Statistics (2024), a significant majority of STEM occupations indeed require postsecondary education, reflecting the advanced knowledge and skills necessary for these roles.

STEM Education and Competitiveness

Moreover, STEM education is crucial for preparing a workforce capable of driving innovation and maintaining economic competitiveness. Despite these challenges, the demand for STEM professionals continues to grow. For instance, projections indicate a 23% increase in STEM job demand by 2030 (Carnevale, et al, 2023). These insights highlight the critical need to rethink and enhance STEM
education methodologies in colleges to produce proficient professionals who can advance health, technology, and overall prosperity in the future.

Educational Reforms

The 1983 report "A Nation at Risk" by the National Commission on Excellence in Education highlighted concerns that the United States was at risk of being outperformed in key areas such as commerce, industry, science, and technology. More recent analyses continue to support the need for educational reform and the impact of educational quality on national competitiveness. The themes of "A Nation at Risk" remain relevant today. The report emphasized the importance of educational standards, accountability, and the need to prepare students for a competitive economy. The focus on high standards and accountability has become central to education reform efforts over the past four decades.

Additionally, the U.S. Government Accountability Office continues to highlight the need for ongoing reforms in various sectors, including education, to address vulnerabilities and inefficiencies. This finding reinforces the idea that systemic improvements are crucial for maintaining national competitiveness and efficiency. The report writers and examiners feared that nations such as Japan would surpass the United States in commerce, industry, science, and technology, leading to deteriorated social and economic conditions and a weakened ability for U.S. workers to compete for high-quality jobs. These concerns were tied to deficits in the educational system, as American public education provides the foundation for achieving the American Dream (Banning & Folkstead, 2011).

America COMPETES Act

The America COMPETES Act (ACA) legislation authorized $2.5 billion to the National Science Foundation (NSF), with at least $100 million for the NSF Human Resources and Education divisions to support educational institutions with teacher training and research to improve math and science in K-12 and higher education. ACA reauthorization in 2010 allocated an additional $6.9 billion annually to the NSF to promote STEM improvements in education at all levels (Carnevale et al., 2023). Furthermore, the U.S. federal government contributed $3.5 billion to federal Pell grants and work-study funding for training in energy efficiency, health, and IT careers (Carnevale et al., 2023).

U.S. Federal Investment in STEM Education

The federal government has continued to support a qualified STEM workforce through legislation such as the America COMPETES Act, providing funding for STEM education. Most federal investment in STEM education supports undergraduate, graduate, and postgraduate education and research. Postsecondary education accounts for more than half of the federal STEM education portfolio. The 2015 American COMPETES Act aimed to increase the pool of highly qualified scientists and engineers within the U.S. (U.S. Congress, 2015). Despite significant federal investment, low retention and graduation rates among STEM undergraduate students remain a challenge, suggesting that factors beyond funding influence these rates (Carnevale et al., 2023).

A significant factor in students transferring out of STEM fields or dropping out altogether is the lack of innovative, equitable, and student-centered teaching practices in STEM education. To improve STEM educational outcomes at higher education institutions, a sustained enhancement in teaching methodologies is crucial. Current research underscores the need for active learning strategies that engage students directly in the learning process. The key teaching strategies identified for their effectiveness include student response systems, project-based learning, case studies, retrieval practice, and peer instruction.

LITERATURE REVIEW

Many of today's educators still follow a traditional teaching approach characterized by teacher-focused instruction with passive students, a method historically rooted in academia. This tradition dates to the establishment of the University of Bologna in 1088 AD, where students received "lectura" (readings). It was not until the advent of the printing press centuries that books became widely available to students, necessitating the faculty to orally convey the information present in handwritten texts (Li et al., 2022).

In the contemporary educational landscape, where knowledge resources are readily accessible, the role of college educators should evolve. Implementing interactive, student-centered pedagogical approaches that facilitate active learning is crucial, particularly given the readiness gap highlighted by the National ACT College Readiness Assessment Report (2023), which reported that only 30% of the 2023 U.S. high school graduates were ready for college-level math and 31% demonstrated readiness for college-level science. This lack of preparedness underscores the need for innovative teaching methodologies to improve STEM graduation rates and ensure that students are equipped for advanced studies.

The following sections will explore innovative teaching methodologies that can effectively transform traditional lectures into interactive, student-centered learning experiences. While many of these approaches have been successfully implemented in various U.S. universities, they often remain isolated initiatives. These methodologies must be discussed, promoted, and widely adopted across educational institutions to stimulate STEM education and improve outcomes.

Classroom Response Systems

Classroom response systems (CRSs), also commonly known as clickers, are electronic response systems that allow individual students in large lecture halls to respond to a question posed by the instructor. The collective responses can then be processed in real-time, providing insight into the students' understanding of specific concepts. Although clickers were initially developed to enhance science and health-related teaching four decades ago (Bessler, 1969), they have gained increasing popularity and are now used in a variety of other disciplines (Keough, 2012).

Initially, CRSs were mainly used to record attendance and gauge comprehension, yet they provide additional advantages, such as improving communication, promoting discussion, stimulating interest, and overall creating an interactive classroom environment. An important feature of CRSs is that they allow each student to contribute to the discussion with virtually no limit on classroom size.

One major limitation of the CRS is the nature of the questions that can be asked. Although modern CRS-based technologies, such as Learning Catalytics™, allow students to submit a wide array of answers, such as numerical, algebraic, textual, graphical responses, or plain multiple-choice answers, this approach is not suitable for stimulating a deep level of learning, as creative questions require more extended answers that cannot be automatically recorded and processed. Therefore, instructors who wish to implement CRS may need to design additional projects to ensure that complex learning outcomes are addressed. Finally, one additional strength of using the CRS is its ability to enhance learning by RP. Retrieval practice involves actively recalling information in response to a question, which has been shown to improve memory retention and understanding better than passive review techniques. By incorporating CRS into their teaching strategies, instructors can promote more active learning and continuous assessment, reinforcing students' grasp of the material.

Retrieval Practice

Retrieval practice, also called test-enhanced learning, is a method that is receiving increasing attention in the educational literature (Dobson, 2019); (Larsen, 2018). This learning strategy consists of the active process of reconstructing knowledge in response to a question (Agrawal et al., 2017). Attempting to remember and reassemble information solidifies knowledge and promotes learning. Initial work on retrieval practice dates back to 1917, when Arthur Gates (1922) reported the importance of recitation for memory and learning. Although this work used recitation as a form of testing and because it is considered a traditional learning technique, this work is considered pioneering in the field because of its implications. Extensive work performed by Spitzer (1939) clarified that it is the effort to recall, and not the mere repetition, responsible for this improved learning.

More recently, retrieval practice has been compared to complex inquiry in the form of concept mapping. O'Day & Karpicke (2021) assert that retrieval practice is just as effective, if not more so than concept mapping used alone. Students were instructed to read relevant biological texts and then engage in retrieval by writing down everything they could remember. After reading the biological texts, the second group only created concept maps about what they read. The third group first created a concept map about what they read and then wrote down what they could remember. Extensive data analysis of the application of retrieval practice showed that 57% of the interventions had moderate to large positive effects on learning. Even greater effects were demonstrated for students with working memory challenges (Agarwal et al., 2016).

Retrieval practice can improve course accessibility for students with working memory challenges such as traumatic brain injury, ADHD, dyspraxia, dyslexia, and language delays. To maximize student learning, educators need to prioritize the consistent implementation of retrieval practices rather than searching for specific optimal conditions related to content areas, formats, or exact timing. Consistency is key.

Retrieval practices also promote engagement. Encouraging students to actively recall and apply knowledge supports fostering deeper understanding and retention of course material. Integrating opportunities for students to reflect on their retrieval practice experiences can also enhance learning and retention with improved metacognition.

Project-Based Learning & Case Studies

Project-based learning (PBL) is a teaching approach in which students develop their knowledge and skills by working on complex questions, problems, or case studies. Case studies were first developed at Harvard Law School in 1870 to bridge the gap between theory and practice (Garvin, 2003). Case-based teaching in medical education began earlier, pioneered by Howard S. Barrows in the 1960s, particularly in medical schools such as McMaster University (Barrows & Tamblyn, 1980). In medical education, Howard S. Barrows pioneered the use of case studies in the 1960s to develop students' clinical reasoning skills. Over time, PBL has evolved beyond these origins, showing significant benefits in various disciplines, including STEM fields.

Project-based learning (PBL) is a teaching approach in which students develop their knowledge and skills by working on complex

questions, problems, or case studies. This method not only enhances understanding but also fosters skills such as critical thinking and collaboration. Research indicates that PBL can play a crucial role in enhancing students' self-efficacy, which refers to their belief in their ability to succeed in specific situations or accomplish tasks. Samsudin et al. (2021) highlighted that students with higher self-efficacy tend to be more engaged and motivated, particularly in tasks requiring extensive cognitive effort. Their study of high school physics students demonstrated that engaging in STEM project-based learning significantly increased students' self-efficacy levels. This boost in self-efficacy positively influenced not only their engagement but also their perseverance in tackling challenging assignments.

Moreover, the World Health Organization (WHO) recognizes PBL as a valuable educational approach (2019). The WHO emphasizes the importance of students selecting a problem to explore and address as their project topic. Students then apply newly acquired skills and concepts to engage in peer discussion and problem solving with real-life examples, whether in person or online, to enhance learning outcomes. They then share their work and receive feedback, integrating learning through practical application. Building relationships is also crucial for facilitating PBL through networking, collaboration, and collective problem solving, and various communication methods, such as learning circles and conference calls, can deepen the understanding of complex problems in STEM.

Despite the proven benefits, concerns remain about the time-intensive nature of PBL and its impact on student collaboration dynamics. Another concern is that PBL may infringe upon the psychological space of some students when they are confronted with working with other individuals or groups. Some individual students may be fearful of whether the other students' contributions or lack thereof to their group projects will affect their own grades. However, in a global economy where students are expected to interact with individuals with a wide range of personalities, backgrounds, and skill levels, the benefits of student collaboration may outweigh the risks associated with the potential stress of PBL on students.

With overwhelmingly long syllabi, adopting a traditional lecture approach may often appear to be the most efficient choice. However, PBL may provide one additional benefit: peer-to-peer instruction and enhanced self-efficacy. By effectively leveraging PBL and case studies, educators can better prepare students for real-world challenges and foster a deeper understanding of complex concepts.

Peer Instruction

Peer instruction is a more recent student-centered teaching methodology that was developed by Harvard physicist Eric Mazur in the early 1990s (Crouch et al., 2007). This is a student-centered learning approach that promotes classroom interaction by engaging groups of students in addressing difficult concepts, usually in the form of conceptual multiple-choice questions. Peer instruction involves seven steps with opportunities for the students to change their answers after discussion.

The students were required to study the material before class to familiarize themselves with the content. Instead of a traditional lecture, the instructor briefly presents each concept and then asks a related question. Students are given a few minutes to individually answer the question before discussing it in small groups. At this point, students are allowed to resubmit their answers before the instructor can explain the correct answer and initiate a new set of question-discussion sessions. On individual physics questions, pre-discussion performance improved on average from 34% to 63% post-discussion after peer instruction was implemented (Crouch et al., 2007).

Although this approach involves the risk of students convincing their peers to support an erroneous answer, it also helps create a relaxed classroom environment that can engage students in stimulating discussions and promote their creative elaboration of the subject material. Overwhelmingly, undergraduate students enrolled in a mathematics analysis course rated peer instruction as particularly effective (Almas et al, 2020) in building positive relations among students (97%). However, 89% believed peer instruction encouraged a supportive classroom environment, and 90-95% rated peer instruction positively as making courses more interesting and engaging for students.

Although we have used scientific reasoning to discuss active learning approaches that may help improve STEM education and the potential for innovation, it is also imperative to mention that teaching has an artistic component. Each instructor needs to develop their own personal teaching style that can spark the students' interest, convey the required information, and mentor them to become thriving STEM professionals.

RECOMMENDATIONS

Start Simple, Expand Strategically: Begin with straightforward activities such as quick recall exercises with Classroom Responses Systems or short quizzes with retrieval practices. As educators gain confidence and experience, they can gradually diversify formats and adapt timing based on their specific teaching context and student needs.

Widely Implemented Retrieval Practice: This research indicates that retrieval practices benefit various conditions and contexts in schools and classrooms. Therefore, educators should feel confident in implementing retrieval practices without overly focusing on identifying "perfect" conditions such as specific content areas, formats, or precise timing.

Adaptability and Flexibility: Peer instruction can be adapted to various educational settings and subject areas, making it a versatile approach for instructors across various disciplines. Its structured yet flexible nature accommodates diverse learning styles and promotes inclusive participation among students.

Promote Active Learning and Engagement: Engage students as active participants in their own learning by integrating research-based teaching strategies such as student response systems, project-based learning and case studies, retrieval practice, and peer instruction. These methodologies encourage students to apply knowledge, solve problems collaboratively, and deepen their understanding through active participation (Freeman et al., 2014).

Monitor Progress and Adapt: Regularly assess student performance and adjust instructional strategies accordingly. This adaptive approach ensures that educators tailor their implementation to maximize learning gains across diverse groups of students.

Address Attrition: The major reasons for students leaving STEM disciplines include difficulty in introductory courses, lack of support and mentorship, and insufficient high school preparation. These issues are exacerbated for marginalized groups due to systemic inequities and inadequate institutional support (Costello et al, 2023).

Strengthening Student Support: Effective institutional support, including accessible advising services and financial aid, is crucial for student retention, especially for underrepresented and low-income students.

Improved funding and strategic support for STEM programs are essential for addressing these retention challenges (Palid et al, 2023).

CONCLUSION

In examining the landscape of STEM education and its impact on global competitiveness, while the number of STEM degrees awarded in the U.S. has been increasing, challenges in retention and global scientific leadership persist. The increasing diversity in STEM fields and the imperative to cultivate a skilled workforce capable of driving innovation necessitate a robust response from educational institutions.

Effective strategies such as peer instruction, project-based learning, retrieval practice, and active learning methodologies have demonstrated their ability to enhance student engagement, comprehension, and retention. These approaches not only foster a deeper understanding of STEM concepts but also prepare students for real-world challenges and collaborative environments critical in today's global economy.

Furthermore, the integration of these innovative teaching methods must be supported by comprehensive institutional reforms. Improving access to quality education, providing tailored support systems, and addressing systemic barriers faced by underrepresented groups are essential steps in fostering inclusive and equitable STEM education. As we navigate the complexities of modern education, it is imperative to emphasize the role of educators in shaping the future STEM workforce.

By embracing evidence-based practices and adapting to evolving educational needs, institutions can better equip students with the skills and knowledge needed to thrive in STEM disciplines and contribute meaningfully to scientific advancements and economic prosperity. "STEM Graduation Trends and Educational Reforms: Analyzing Factors and Enhancing Support" serves as a call for stakeholders in academia, policy, and industry to collaborate on creating an environment where all students can succeed and contribute to a globally competitive STEM landscape.

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