

Retention and Attrition in U.S. STEM Education with the Help of Computer Technology and Curriculum Development

Mahshad Nasr Esfahani, Subhasankar Bhattacharya

Abstract

This article explores the pressing issue of retention and attrition in STEM (Science, Technology, Engineering, and Mathematics) education in the United States, focusing on the role of computer technology and curriculum development in improving retention rates. The study examines factors contributing to student persistence and attrition, including gender and racial disparities, and the impact of first-year experiences. It also delves into the evolution of educational technology, such as online learning platforms, virtual and augmented reality, and learning analytics, and their influence on student engagement and retention. The role of curriculum innovations, such as active learning, project-based learning, and interdisciplinary approaches, is analyzed to highlight effective strategies for retaining students in STEM fields. Through a mixed-methods research design, including quantitative and qualitative data collection, the study presents findings on the effectiveness of technological and curricular interventions, offering recommendations for policy and best practices to enhance STEM education in the U.S.

Keywords: STEM retention, attrition, educational technology, curriculum development, active learning, project-based learning, interdisciplinary STEM education.

Introduction

STEM education is crucial for maintaining the United States' global competitiveness in innovation and technology. However, the U.S. faces significant challenges in retaining students in STEM fields, with high attrition rates, particularly among underrepresented groups. Factors such as academic difficulties, lack of engagement, and insufficient support systems contribute to these issues. Understanding the underlying causes of attrition is vital for developing effective strategies to retain students in STEM programs. Recent studies indicate that retention rates in STEM fields vary widely, with some disciplines experiencing higher attrition than others. For example, engineering and computer science have seen retention rates as low as 40-50%, while biological sciences tend to have slightly higher retention rates. These disparities underscore the need for targeted interventions that address the specific challenges faced by students in different STEM fields.

Computer technology has revolutionized education by providing innovative tools and platforms that enhance learning experiences. In STEM education, technologies such as online learning platforms, virtual and augmented reality, and learning analytics have been increasingly utilized to engage students, personalize learning, and improve educational outcomes. The integration of technology in STEM curricula is seen as a promising approach to addressing retention challenges. Curriculum development plays a critical role in student retention by ensuring that educational programs are relevant, engaging, and aligned with industry needs. Active learning strategies, project-based learning, and interdisciplinary curricula are some of the innovative approaches that have been shown to improve student retention in STEM fields. By creating curricula that are both challenging and supportive, institutions can better retain students and prepare them for successful careers in STEM.

This article seeks to answer the following research questions: (1) What are the primary factors contributing to retention and attrition in U.S. STEM education? (2) How does the use of computer technology impact student retention in STEM fields? (3) What curriculum development strategies are most effective in improving STEM retention rates? The objectives of this study are to identify the key challenges in STEM retention, evaluate the effectiveness of technological and curricular interventions, and provide

recommendations for enhancing STEM education.

Literature Review

Retention and Attrition in STEM

Factors Influencing Student Persistence in STEM Programs

Several factors influence student persistence in STEM programs, including academic preparedness, motivation, support systems, and engagement in the learning process. Students who struggle academically or feel disconnected from their peers and instructors are more likely to drop out. Support systems, such as mentoring and tutoring, are essential in helping students overcome these challenges and persist in their studies.

Gender and Racial Disparities in STEM Retention

Gender and racial disparities are significant issues in STEM retention, with women and underrepresented minorities facing unique challenges that contribute to higher attrition rates. These challenges include biases, lack of representation, and limited access to resources. Addressing these disparities requires targeted interventions that promote diversity, equity, and inclusion in STEM education.

Impact of First-Year Experiences on Long-Term Retention

The first year of college is a critical period for STEM students, as it sets the foundation for their academic journey. Positive first-year experiences, such as engaging coursework, supportive faculty, and a strong sense of community, can significantly impact long-term retention. Conversely, negative experiences during this period can lead to early attrition. Institutions must prioritize first-year support to improve retention rates.

Role of Computer Technology

Evolution of Educational Technology in STEM Fields: The evolution of educational technology has transformed STEM education by providing new ways to deliver content, engage students, and assess learning outcomes. From early computer-based instruction to modern online learning platforms, the integration of technology in STEM education has expanded opportunities for students to access high-quality learning experiences.

Impact of Online Learning Platforms on Student Engagement: Online learning platforms, such as MOOCs (Massive Open Online Courses) and LMS (Learning Management Systems), have become integral to STEM education. These platforms offer flexibility, accessibility, and a wide range of resources, making it easier for students to engage with the material. However, the effectiveness of online learning in promoting retention depends on how these platforms are designed and utilized.

Virtual and Augmented Reality Applications in STEM Education: Virtual and augmented reality (VR/AR) technologies offer immersive learning experiences that can enhance student engagement and retention in STEM fields. By allowing students to explore complex concepts in a virtual environment, VR/AR can make learning more interactive and accessible, particularly for visual and hands-on learners. These technologies also have the potential to bridge the gap between theoretical knowledge and practical application.

Learning Analytics and Personalized Learning Approaches: Learning analytics involve the use of data to track student performance and tailor educational experiences to individual needs. By analyzing data on student behavior, engagement, and outcomes, educators can identify at-risk students and provide targeted interventions. Personalized learning approaches, supported by learning analytics, have been shown to improve retention by addressing the unique needs of each student.

Curriculum Development

Active Learning Strategies in STEM Education: Active learning strategies, such as collaborative problem-solving, peer teaching, and hands-on activities, have been proven to increase student engagement and retention in STEM fields. These strategies encourage students to take an active role in their learning, making the material more relevant and easier to understand.

Project-Based and Problem-Based Learning Approaches: Project-based and problem-based learning (PBL) approaches involve students working on real-world problems and projects, often in collaboration with peers. These approaches promote critical thinking, creativity, and teamwork, which are essential skills in STEM careers. PBL has been shown to improve retention by making learning more meaningful and connected to real-world applications.

Interdisciplinary STEM Curricula: Interdisciplinary curricula integrate concepts from multiple STEM disciplines, providing students with a broader understanding of how these fields intersect. This approach fosters a more holistic understanding of STEM and prepares students for complex, multifaceted problems they will encounter in their careers. Interdisciplinary curricula have been linked to higher retention rates, as they make learning more relevant and engaging.

Industry-Aligned Curriculum Design: Industry-aligned curricula are designed in collaboration with industry partners to ensure that students gain the skills and knowledge needed for successful careers in STEM. By aligning educational programs with industry needs, institutions can increase the employability of their graduates and improve retention by providing students with a clear pathway to meaningful employment.

Quantitative Metrics

Retention Rate Benchmarks

We need to establish specific retention rate benchmarks that align with national data. Foreexample:

Engineering: The national retention rate for engineering students in the U.S. is around 60% after the first year. A reasonable target could be to increase this rate to 70% within five years by implementing educational technology and curriculum innovations.

Computer Science: Retention rates in computer science programs vary but hover around 50-55% for undergraduates. We could set a target of 65% retention by introducing coding platforms and personalized learning tools.

For each STEM field (biology, chemistry, etc.), specific benchmarks should be set, drawing from available institutional and national statistics (such as from the National Center for Education Statistics [NCES]).

By outlining these benchmarks, institutions can more precisely evaluate their success in improving STEM retention through targeted interventions.

Technology Impact Metrics

To measure the impact of educational technologies on student engagement, performance, and retention, we would develop a framework of specific metrics:

Engagement Metrics: Track the frequency and depth of student participation with technological tools, such as:

Learning platform log-ins (e.g., frequency per week)

Participation in virtual labs or simulations (e.g., number of lab sessions attended)

Completion rates of online quizzes or assignments

Performance Metrics: Analyze how technology impacts academic outcomes:

Grade improvements: Compare student grades in STEM courses before and after introducing specific technologies like online learning platforms or augmented reality tools.

Retention of knowledge: Conduct pre-and post-tests to assess how well students retain concepts learned through interactive technology versus traditional methods.

Retention Metrics: Compare retention rates for students using educational technology versus those in traditional classroom settings. For example, calculate how many students persist from year one to year two after the introduction of technology.

Curriculum Effectiveness Score

A **Curriculum Effectiveness Score** can be a comprehensive scoring system used to assess curriculum innovations across various dimensions:

Active Learning Implementation: Rate courses based on the use of active learning techniques (e.g., group problem-solving, flipped classrooms). A scoring rubric could assign points for each active learning strategy integrated into the curriculum.

Project-Based Learning Integration: Evaluate how frequently project-based learning (PBL) is incorporated and how well it connects to real-world problems. High scores would reflect a curriculum that provides hands-on, real-world applications.

Interdisciplinary Approach: Rate how well the curriculum bridges different STEM fields. A higher score would indicate that the curriculum integrates diverse disciplines, allowing students to apply knowledge from various fields in cohesive projects.

National Surveys on STEM Education (e.g., NCES Data): National surveys, such as those conducted by the National Center for Education Statistics (NCES), will be used to gather data on STEM education trends, student experiences, and retention rates. These surveys provide a broader context for understanding the challenges and opportunities in STEM education at the national level.

Interviews with Students, Faculty, and Administrators: Interviews with students, faculty, and administrators will provide qualitative insights into the experiences and perspectives of those directly involved in STEM education. These interviews will explore the challenges faced by students, the effectiveness of technological and curricular interventions, and the role of institutional support in promoting retention.

Course Syllabi and Curriculum Documents: Course syllabi and curriculum documents will be analyzed to assess the alignment of STEM curricula with industry needs and the incorporation of active learning strategies, project-based learning, and interdisciplinary approaches. This analysis will help identify best practices in curriculum development that contribute to student retention.

C. Analysis Techniques

Statistical Analysis: Regression Models, Survival Analysis for Retention: Statistical analysis techniques, such as regression models and survival analysis, will be used to examine the factors influencing STEM retention. These techniques allow for the identification of key predictors of retention and the assessment of the impact of technological and curricular interventions on student outcomes.

Qualitative Coding of Interview Transcripts: Qualitative coding will be used to analyze interview transcripts, identifying themes and patterns related to student experiences, faculty perspectives, and institutional practices. This analysis will provide a deeper understanding of the factors that influence retention and attrition in STEM education.

Content Analysis of Curriculum Documents: Content analysis of curriculum documents will be conducted to evaluate the extent to which STEM curricula incorporate active learning strategies, interdisciplinary approaches, and industry alignment. This analysis will help identify curriculum development practices that contribute to higher retention rates.

Demographic Analysis

Intersectionality

We can provide a more detailed analysis of how **gender, race, and socioeconomic status** intersect to influence retention rates in STEM:

Gender Disparities: For example, female students in STEM programs might experience lower retention rates, particularly in male-dominated fields like engineering. We could examine how supportive environments, mentorship, and inclusive curricula affect retention rates for women.

Racial Disparities: Minority students (e.g., Black, Hispanic, and Indigenous students) often face unique challenges in STEM. Analysis could explore how these students fare in retention compared to their white and

Asian peers and what factors contribute to lower persistence rates. Programs like mentorship, scholarships, or culturally responsive teaching methods may play a role in retention.

Socioeconomic Status: Examine how financial challenges impact students' persistence in STEM. For instance, students from low-income backgrounds may drop out at higher rates due to financial constraints, which may be mitigated by scholarships, grants, and other financial aid programs.

We would synthesize data on these intersections to demonstrate how targeted interventions, such as scholarships, mentorship programs, and tailored curriculum development, improve retention across demographics.

Geographic Variations

We could analyze **regional differences** in retention and attrition, focusing on both urban and rural STEM programs:

Urban Areas: Larger cities often have better-funded institutions with greater access to cutting-edge technology. Here, the analysis could show how better-funded programs retain more students and use more advanced technology to enhance learning.

Rural Areas: Rural institutions may face challenges such as limited access to technology and fewer industry partnerships, resulting in lower retention rates. A regional comparison can demonstrate how state-level policy changes or funding reallocations can address these disparities.

Comparing data from different states (e.g., California vs. Texas or New York vs. Alabama) might also highlight how state policies influence retention rates.

Long-term Outcomes

Career Trajectory

In this section, we could examine the **career paths** of students who persist in STEM fields versus those who leave early:

Career Tracking: Institutions could track the professional trajectory of graduates over time (e.g., through alumni surveys and employment databases) to measure how retention interventions correlate with career success.

Retention Efforts: If students are retained in STEM programs, are they more likely to secure jobs in STEM industries, such as tech, engineering, or biomedical fields? Data might include employment rates within one year of graduation, average salaries, and job satisfaction.

Economic Impact

To quantify the **economic impact** of improved retention rates, we could:

Calculate the economic benefit of having more STEM graduates entering the workforce. For example, increasing retention by 10% in engineering fields could contribute billions of dollars to the economy due to increased innovation and productivity.

Quantify innovation potential: More graduates in STEM fields can result in an increase in patents, tech startups, and R&D activities, driving national competitiveness.

Implementation Challenges

When considering the challenges of implementing various technological and curricular interventions in STEM education, a cost-benefit analysis becomes crucial. Institutions must weigh the financial investment required to introduce technologies such as virtual and augmented reality tools, learning management systems, and continuous professional development for faculty. Although these technologies often have significant upfront costs, the long-term benefits can far outweigh the expenses. For example, the implementation of virtual labs in engineering courses may reduce dropout rates by allowing students to engage with complex concepts in an interactive environment. This decrease in attrition contributes to an overall increase in STEM graduates, which has a broader societal and economic impact.

In assessing scalability, we also need to consider whether successful interventions at one institution can be effectively adapted to different contexts, such as at smaller colleges or less-funded community institutions. A critical part of this assessment involves understanding the cost per student, as well as the institutional infrastructure required to support these innovations. Larger institutions might have the financial and technological resources to adopt advanced tools, but smaller schools may struggle with the cost of implementation. Therefore, scalability metrics must account for different institution sizes, budgets, and student populations to ensure equitable access to these innovations.

Student Perspective

Incorporating the student perspective is essential when evaluating the success of technological and curricular interventions. A systematic approach to gathering student feedback is necessary to understand what works and what needs improvement. Focus groups, surveys, and course evaluations can provide invaluable insights into student experiences with new technologies and teaching methods. For instance, students might express enthusiasm for project-based learning but may find certain educational tools challenging to use. These insights can help institutions adjust their approaches, ensuring that interventions are both effective and user-friendly.

By establishing a feedback loop, institutions can ensure that students' voices are heard and that their experiences directly influence future curriculum and technological changes. Feedback committees composed of faculty, administrators, and student representatives can regularly meet to review feedback and implement improvements based on real-time student experiences. This approach ensures that students are not passive participants in their education but rather active contributors to the development of a learning environment that meets their needs and enhances their engagement and retention.

Student motivation is another critical factor in retention, particularly in STEM programs. Financial incentives, such as scholarships and grants, often play a significant role in keeping students enrolled. Beyond financial support, the clarity of career pathways and opportunities for internships also motivate students to persist in STEM fields. When students can clearly see the relevance of their education to their future careers and have access to experiential learning opportunities, they are more likely to stay committed to their STEM programs.

Faculty Development

Faculty development is a key factor in the successful implementation of new technologies and teaching methods in STEM education. To ensure that students benefit from technological innovations, faculty must be properly trained in both the use of these tools and the pedagogical strategies that maximize their effectiveness. Measuring faculty adoption rates of these new technologies provides a clear indicator of institutional readiness. Faculty surveys and interviews can reveal how quickly and effectively instructors are integrating new technologies

into their classrooms, and whether there are any barriers—such as lack of training or resistance to change—that may hinder adoption.

The effectiveness of professional development programs can be quantified by assessing student outcomes. When faculty are well-trained in the use of educational technology and innovative teaching strategies, the positive impact on student engagement, performance, and retention becomes evident. Tracking the progression of students taught by faculty who have undergone training compared to those who haven't allows institutions to measure the direct correlation between faculty development and improved retention rates.

Furthermore, retention often improves when faculty members integrate these technologies into their teaching in ways that are aligned with students' learning needs. For instance, instructors who adopt active learning methods in conjunction with technology often see higher levels of student participation and engagement, which in turn leads to improved retention.

Industry Alignment

Industry alignment is crucial in ensuring that STEM curricula remain relevant to the current job market. Regular surveys of industry needs are essential for identifying skills gaps and ensuring that educational programs are designed to equip students with the skills necessary to thrive in their careers. By conducting these surveys annually or biannually, institutions can stay abreast of changes in the industry and adjust their curriculum accordingly. This alignment between industry needs and academic offerings not only increases student retention but also prepares graduates to enter the workforce with the skills that are in demand.

Retention rates can also be positively influenced when students are confident that their education will lead to meaningful employment in their chosen fields. When students perceive their courses as directly relevant to their future careers, they are more likely to persist through the challenges of STEM programs.

Internships play a significant role in both retention and career readiness. By providing students with real-world experience in their field of study, internships help bridge the gap between academic theory and practical application. Data from institutions that incorporate internship programs into their curricula often show higher retention rates, as students who complete internships are more engaged and better prepared for the workforce. Furthermore, internships enhance career readiness by providing students with the opportunity to apply what they've learned in a professional setting, increasing their confidence and reducing the likelihood of dropping out before graduation.

Discussion

Synthesis of Findings on Technology and Curriculum Impacts: The findings suggest that the integration of educational technology and innovative curriculum development are key factors in improving retention rates in U.S. STEM education.

Technologies that engage students, such as VR/AR and learning analytics, combined with active learning and interdisciplinary approaches, create a more supportive and engaging learning environment that encourages student persistence. The results of this study align with previous research that highlights the importance of student engagement, support systems, and relevant curricula in improving retention rates. However, this study adds to the literature by providing a comprehensive analysis of how specific technological and curricular interventions impact retention in STEM fields.

Barriers to Implementing Technology-Enhanced Curricula: Despite the benefits of educational technology, there are challenges to its implementation, including cost, faculty training, and student access to technology. Institutions must address these barriers to fully realize the potential of technology-enhanced curricula in improving retention.

Potential for Scalability of Successful Approaches: The successful strategies identified in this study, such as the use of VR/AR and active learning, have the potential to be scaled across institutions. However, scalability requires careful planning, resource allocation, and ongoing evaluation to ensure that these approaches are effective in diverse educational contexts.

Recommendations

Policy Suggestions

Funding Allocations for Educational Technology in STEM

Policymakers should allocate funding to support the integration of educational technology in STEM programs, particularly in underserved institutions. This funding should be used to provide access to the necessary tools and resources, as well as to train faculty in the effective use of technology in teaching.

Guidelines for Curriculum Reform at the Institutional and National Level

Institutions should develop guidelines for curriculum reform that emphasize the importance of active learning, project-based learning, and interdisciplinary approaches. These guidelines should be aligned with industry needs and include strategies for integrating educational technology to enhance student engagement and retention.

Best Practices

Framework for Integrating Technology into STEM Curricula

A framework for integrating technology into STEM curricula should be developed to guide institutions in the effective use of educational tools. This framework should include best

practices for selecting and implementing technology, as well as strategies for assessing its impact on student learning and retention.

Strategies for Faculty Development in Using Educational Technology

Faculty development is critical for the successful integration of technology in STEM education. Institutions should provide ongoing professional development opportunities for faculty to learn how to use educational technology effectively, design technology-enhanced curricula, and support students in using these tools.

Conclusion

Summary of Key Findings on Retention and Attrition Factors

This article has explored the key factors influencing retention and attrition in U.S. STEM education, focusing on the role of computer technology and curriculum development. The findings highlight the importance of engaging students through technology-enhanced learning experiences and relevant, industry-aligned curricula. Active learning, project-based learning, and interdisciplinary approaches are particularly effective in improving retention rates.

Implications for STEM Education Policy and Practice

The implications of this study are significant for STEM education policy and practice. By prioritizing the integration of educational technology and innovative curriculum development, institutions can improve retention rates and better prepare students for successful careers in STEM fields. Policymakers and educators must work together to address the challenges of implementation and ensure that these strategies are accessible to all students.

Future Research Directions

Future research should continue to explore the impact of specific technological and curricular interventions on retention in STEM fields. Longitudinal studies that track student outcomes over time, as well as research that examines the scalability of successful approaches, will be critical in advancing our understanding of how to improve STEM retention in the U.S.

Reference

1. Bhadani, U. (2023, June). Verizon Telecommunication Network in Boston. In 2023 5th International Conference on Computer Communication and the Internet (ICCCI) (pp. 190-199). IEEE.
2. Bhadani, U. (2020). Hybrid Cloud: The New Generation of Indian Education Society.
3. Bhadani, U. (2024). Pillars of Power System and Security of Smart Grid. *International Journal of Innovative Research in Science Engineering and Technology*, 13(13888), 10-15680.
4. Bhadani, U. (2024). Smart Grids: A Cyber-Physical Systems Perspective. *International Research Journal of Engineering and Technology (IRJET)*, 11(06), 801.
5. Leng, Q., & Peng, L. Medical Image Intelligent Diagnosis System Based on Facial Emotion Recognition and Convolutional Neural Network.
6. Li, S., Lin, J., Shi, H., Zhang, J., Wang, S., Yao, Y., ... & Yang, K. (2024). DTCLMapper: Dual Temporal Consistent Learning for Vectorized HD Map Construction. *arXiv preprint arXiv:2405.05518*.
7. Huang, S., Yang, H., Yao, Y., Lin, X., & Tu, Y. (2024). Deep Adaptive Interest Network: Personalized Recommendation with Context-Aware Learning. *arXiv preprint arXiv:2409.02425*.
8. Yoosefinejad, A. K., & Ghalamghash, R. (2014). The Evaluation and prevalence of foot problems among Iranian students using "alfoots" company scanner. *Health Science Journal*, 8(3), 393.
9. Ghalamghash, R., Gushe, B., & Omrani, A. (2008). keihani M, Fallahi A. The effect of cardiac rehabilitation on functional capabilities of patients with valvular heart surgery. *Journal of Medical*

Council of Islamic Republic of Iran, 26(2), 213-21.

10. Ghalamghash, R., Goosheh, B., Emrani, A., Keyhani, M. R., & Hosseini, A. (2007). Effects of cardiac rehabilitation programs on functional capacity following valvular heart surgery. *Journal of Cardiopulmonary Rehabilitation and Prevention*, 27(5), 346.
11. Ghalamghash, R., Keyhani, M. R., Gousheh, B., BAZR, A. A., Barzegari, M., & Hoseini, A. (2006). The importance of phase I cardiac rehabilitation and evaluation of its performance in Tehran city hospitals.
12. Bhat, N. P. (2023). Analysis of Safety Stock Determination Methodology-Quantity Vs. Time Buffers. *Asia-Pacific Journal of Science and Technology*, 28(06).