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Cover Page Footnote

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STEM Education in College: An Analysis of Stakeholders' Recent Challenges and Potential Solutions

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Abstract

A vast majority of academic disciplines and curricula in the college center around Science, Technology, Engineering, and Mathematics (STEM), which are critical to developing the skills necessary for a global workforce. Rapid changes in pedagogical setups, educational modes, and advances in instructional technology entail diverse challenges for key stakeholders (i.e. students, faculty, and the organizations). This paper highlights the most relevant challenges and potential solutions in STEM higher education at the college level, reported in the last decade. The holistic analysis combining the three stakeholders' perspectives would help elucidate significant contemporary aspects impacting the fields. The goal is to further understand the factors impeding expected learning outcomes. This would help identify as well as bridge the gaps among these three pillars of instruction, possibly forming a foundation for improved content, delivery, and efficacy of higher education in STEM.

Keywords: STEM education, college, stakeholders, challenges, solutions.

Introduction

The need to modernize undergraduate and graduate education in Science, Technology, Engineering, and Mathematics (STEM) in the United States has been discussed since the last century. In 1995, a major report of the National Academies of Sciences, Engineering, and Medicine highlighted how the U.S. system was even then lagging trends in student interests and career plans and the ways STEM fields evolve. Twenty reports later, there have been some, but not much, progress made. The urgency of the need for change is more evident in our times. We recently presented this topic at the Florida Distance Learning Association (FDLA) Annual Conference 2020 (Arguello et al., 2020). Expanding upon the work, this paper aims at reviewing critical, contemporary challenges or barriers to STEM education from the perspectives of the major stakeholders – students, faculty, and educational institutions, and suggest relevant solutions/drivers for improvement.

Stakeholders' Recent Challenges and Potential Solutions in College STEM Education

Students

Central to the stakeholders of college STEM education are students, who are faced with a wide array of challenges ranging from in-person or remote instructional aspects to active, engaged learning and real-world application of the concepts they acquire. These challenges, and suggested solutions, are underscored below.

Key Student Challenges in Face-to-Face Classes. In a pertinent study, academic deans of select U.S. universities were inquired about the kind of challenges new STEM students are currently tackling (https://www.worldwidelearn.com/education-advisor/officehours/challenges-in-stem.php). Background in Mathematics and Science has been reported to be the most frequent and significant challenge that students face. Having taken advanced math, chemistry, and physics high school courses are beneficial for students to perform adequately in the gateway courses needed by STEM disciplines. On the other hand, despite the rapid evolution of STEM disciplines, the pedagogical approaches in these disciplines are not changing as much. Novel discoveries have become a cross-disciplinary process, and modern science is most active at the interface between disciplines, requiring individuals from multifaceted backgrounds with varied perspectives to solve complex problems. Unique challenges are associated with STEM education for students as well as teachers. For instance, unlike history or philosophy, the STEM landscape is undergoing continuous and rapid changes. Several current areas of expertise have come to the forefront in recent times, which did not exist earlier. To stay relevant in midst of such volatile technology, STEM disciplines require students and teachers to be constantly updated and productive to prevent their education from becoming outdated. Furthermore, STEM students need to master technically complex material such as mathematical and scientific concepts which can necessitate students to demonstrate a working knowledge of the content taught. New strategies are being investigated to teach better and assess the mastery of students in face-to-face Science courses; for instance, implementation of research-based curricula in student Biochemistry labs through the Biochemistry Authentic Scientific Inquiry Learning (BASIL) model, a sample Course-based Undergraduate Research Experience (CURE) (Kim, Haughton, et al., 2020; Kim, Muchintala, et al., 2020).

The unique practices and cultures existing in STEM classrooms can potentially shape students’ acceptance of challenges and failures, during and after their years of STEM education. A recent model hypothesized various ways in which students might deal with challenges and cope adaptively with failure in undergraduate STEM educational perspectives by analyzing mindset, attributions, fear of failure, goal orientations, and coping (Henry et al., 2019). This is particularly important since only limited information exists on how undergraduate students develop a persevering and challenge-engaging disposition within STEM contexts, as a critical step in the path to successful STEM careers.

Online Student Challenges. Online education and the science of learning are two parallelly running potential revolutions with unconnected tracks (Bonvillian & Singer, 2013). These could lead to a fundamentally different system of higher education and need to be united to optimize both. Properly conducted online assessment can provide much insight into learning and help reform online and face-to-face modes of instruction. To attain such goals and improve online as well as traditional classroom education, systematic application of what is known and what is learned in the future about learning science would be essential. Ideally, the U.S. will implement a holistic system, with online education providing information to augment data visualization and foster critical assessment, complemented by face-to-face academe that promotes mentoring, discourse, argumentation, conceptual interactions, and training students for research. Judicious amalgamation of such a human-online symbiosis ensuring an all-inclusive educational environment encompassing teachers, students, and teams with online skillset is would facilitate science learning.

The devastating and ongoing Coronavirus Infectious Disease 2019 (COVID-19) has impacted practically most levels and sectors of education (De, 2020b). In light of the pandemic-led transition of in-person classes to online mode, prominent representative examples of concerns expressed through personal communications by undergraduate Science students (anonymous, unidentified) of a Biology (Pre-Medical) major course at a large university in South Florida, during the winter 2020 term, along with corresponding justifications by the course instructor in response to the student-comments, are presented in Table 1.

Table 1
Student concerns and faculty responses in an undergraduate Biology major course after rapid shift to online instructional mode as a result of COVID-19 pandemic

Student Concerns	Faculty Responses
"(It) was amazing while we were still in the class in person, the in-person labs also help a lot. The course got significantly harder once switched to online."	"The course content and level of difficulty remained the same; it might have been due to the faculty still adjusting to the drastic transition to the new mode of instruction and getting accustomed to the technological aspects, or the student's perspective based on his/her level of preparation, adaptability to the new learning environment, or due to mental/emotional stress from the pandemic."
"I wish we could go back to the test questions online rather than submit and move on to the next and not being able to check your work."	"Online exams were set that way consistently for all sections of the course taught by all instructors, to prevent cheating."
"Online tests were very different from what was before given in person."	"Science courses' online tests use Pearson or other learning and assessment platforms, offering a variety of questions. Online tests may need to be fixed within a tight time-window and no option of changing answers. Also, students are asked to make themselves visible on Zoom during an online test with possible Respondus and/or Lockdown browser usage to proctor efficiently and prevent plagiarism."
"I would recommend more case study practice during lecture and lab to promote further clinical and abstract learning."	"Students were given sample/practice questions, case studies, patient problems, etc. during in-person/online classes and review sessions. However, there is always room for improvement, and the transition in winter 2020 did not allow much time on teachers' or students' end to prepare with more such resources as it was done mid-semester, within a week's notice."

Note: This table demonstrates representative student concerns in an undergraduate Biology (Pre-Medical) major course at a not-for-profit, private university in South Florida, upon the COVID-19-based online transition in the winter 2020 term, addressed specifically by the course instructor.

Need for Active Learning and Real-World Application. One of the main drivers that impact students' interest in STEM is the availability and accessibility of tools for hands-on experience with real-life, STEM-based problems. Providing a social context and a narrative to STEM content is particularly successful in attracting students to STEM higher education programs. Students, especially girls, start losing interest in STEM by the time they are in high school, demanding a focus on sustaining or increasing that interest during those formative years, which could be achieved with innovative digital learning/engagement tools such as mobile apps during teenage (De & Nethi, 2019; Nethi & De, 2019) or in college (Nethi & De, 2020), or even the recently developed virtual classrooms for healthcare sciences in higher education (De & Cavanaugh, 2020).

Academic instruction suffers from silo thinking philosophy which hinders active, experiential learning among students (Portz, 2015). It does not consider how students learn best nor recognize the importance of practical application of the knowledge they gain. Students need to be allowed the opportunity of leveraging the education to learn, collaborate, or produce a project by utilizing appropriate technology. The effectiveness of a STEM program fundamentally relies on making STEM education a medium for workforce development, by teaching our students the necessary workplace skills, integrated, applied, and contextual, as used in the real world.

Faculty

The STEM landscape is constantly changing. The STEM faculty, who prepare and train the undergraduate and graduate students in the field, present unique challenges. Rapid innovations in research methods and technologies, radical changes in the nature and availability of work, shifts in demographics, and expansions in the possibility of occupations needing STEM expertise to raise questions about how well the existing STEM undergraduate and graduate education system is meeting the full array of 21st century needs.

Faculty members are the front line of higher education, playing the key role in fostering the next generation of STEM professionals as educators, mentors, and advisors. Fairweather (Fairweather, 2008) determined that STEM faculty members showed an inadequate use of teaching practices or pedagogical techniques. Improving student's learning requires a shift in the STEM teaching culture, which entails shifting teaching standards. Faculty that teach STEM courses face numerous challenges such as lack of adequate faculty professional development (PD), teaching online and blended STEM courses, and the need to shift teaching practices in STEM education courses.

Lack of Adequate Professional Development for STEM Faculty. Faculty PD is a key strategy for improving STEM education in colleges and universities across the U.S. Most STEM faculty begin their teaching careers with very little professional training in teaching and in delivering effective teaching practices (Hilborn, 2012). Much higher education faculty that teach in STEM majors, follow teacher-center pedagogies such as lectures, as the main method of instruction (Borda et al., 2020). According to (Laursen, 2019), most STEM academics with a doctorate have little formal training in teaching and learning. Furthermore, faculty PD in college STEM should change toward more student-centered methods (Laursen, 2019).

Borda et al. (2020) remark the following conditions for change: (a) transformation of research on teaching and learning into actionable measures to enhance practice, (b) implementation of long-germ contributions, (c) interventions that seek to change the opinions of participants, and (d) multiple parallel programs. The PD of STEM faculty has been improperly executed in various ways, causing its results to be additive rather than cooperative (https://www.aacu.org/diversitydemocracy/2017/fall/mack). Many STEM faculty members have indicated they feel more formal and structured training is needed to change the way they teach (Brownell & Tanner, 2012). Therefore, PD for STEM faculty needs to be an ongoing process to create the necessary change and be able to move towards a more student-centered pedagogy. One-day or one-week national or regional workshops might not be enough for STEM faculty to implement new teaching practices in the classroom (Brownell & Tanner, 2012).

There is a need for PD that uses the curriculum and allows the gain of experience with STEM concepts and the pedagogy in a meaningful way Curricular change initiative can present modern practice in STEM education (Hilborn, 2012). Czajka and McConnell (Czajka & McConnell, 2016) did a case study that documents the use of a situated instructional coaching process, as a method of faculty professional development. In this model, a geoscience education graduate student (the coach) assisted a faculty member in reforming and teaching an introductory geoscience course on dinosaurs using evidence-based teaching strategies. The results of this study demonstrate that the instructor was successful in teaching the lessons as designed and gained skills in creating reformed lessons. Further, this coaching model served as an effective technique for professional development for the instructor.

Faculty development programs in STEM education should not only focus on junior faculty but also, on senior faculty to continue enhancing the curriculum and the teaching practices. For instance, with the rapid transition to online teaching because of the pandemic, most STEM faculty that taught face-to-face courses had to take PD workshops, in online teaching and learning, to adapt to the new norm and help the students transition to the distance learning environment. STEM faculty recommend partnership-based PD programs, facilitating dialogue between science and math professors with engineers, about STEM applications and activities (Portz, 2015).

The Challenge of Teaching Online and Blended STEM Courses. Colleges and universities in the U.S. are starting to acknowledge that they need to develop a new blended model, with a new, more dynamic role for faculty. Face-to-face learning will survive only if it uses the exclusive strengths that it can gather in expression, written analysis, and performing learning-by-doing research. Asking higher education, which has been historically averse to innovation, to pursue two simultaneous major education reforms—online and blended—is asking a lot. However, it may over time prove the only move (Bonvillian & Singer, 2013). The volatility of the technology powering many STEM disciplines means students and teachers must stay diligent or else let their education may become obsolete (El-Deghaidy & Mansour, 2015). When designing online or blended STEM courses, the three possible models of instruction of an interdisciplinary curriculum (parallel, cross-disciplinary, and infusion) should exist (El-Deghaidy & Mansour, 2015). Further, embedding aspects of experiential learning and active learning in STEM online and blended courses may help faculty promote student-centered practices (Mutambuki et al., 2020). Faculty should develop, adopt, and regularly evaluate the strategies they use in their online and blended courses to improve equity and inclusion and do the necessary interventions to prevent late-stage attrition.

The Need to Shift Teaching Practices in STEM Education Courses.

According to Portz (2015), STEM education intends to shift teaching practices from traditional lecture-based teaching into those that are inquiry, project-based, and problem-based learning, as a way to present interdisciplinary, meaningful learning experiences that could include two or more of the four main disciplines identified in STEM education. Improving students learning demands a change in the STEM teaching culture (Shadle et al., 2017). These authors did a study where faculty indicated as challenges to shift in teaching norms, time constraints and not being able to cover all of the course content, other classroom management issues, class sizes, and meeting the diversity of students' expectations and classroom configurations. Faculty members realize that STEM education promotes 21^{st}-century skills, including thinking skills, collaboration, problem-solving, and research skills (Portz, 2015).

Higher Education Institutions

The STEM field is in a crisis mode and teaching through a crisis requires a radical new mindset as the rules have changed in academia. One of the main goals of higher education institutions that offer STEM education programs is to improve the quality of undergraduate and graduate teaching and student learning in these disciplines. Colleges and universities in the U.S. are experiencing a decline in enrollment of students pursuing a major in STEM areas. Further, they are experiencing high attrition rates and a drop of STEM undergraduate students (Fairweather, 2008). There are several challenges higher education institutions are currently facing. In this article, we will focus on explaining the following challenges: student retention and attrition, cost-effective programs and innovative learning platforms, and the lack of funding for interdisciplinary research.

Student Retention and Attrition. A comprehensive review in 2003 interpreted and clarified the interrelationship of the features of undergraduate Science education programs due to which they continually see high rates of attrition among first-year college STEM majors (Daempfle, 2003). Instructional factors, varying expectations by high school and college faculty for entering STEM undergraduates, and epistemological considerations could interact with one another, aggravated by large class sizes and cognitive variables, to contribute to greater dissatisfaction noted among STEM majors students, leading to the loss.

It has been proposed that attrition from a STEM discipline may be due to factors entirely unrelated to a student's intellectual capacity (Emekalam, 2019). Detecting such factors and addressing them using cultural and institutional upliftment may reduce the lack of enrollment, strengthen retention, and result in a better rate of graduation in the discipline. This paper insisted on a pressing need for STEM departments to re-evaluate the curricular and co-curricular support systems available for students with overwhelming academic loads.

Numerous STEM entrants eventually change majors to non-STEM disciplines, perform poorly, and/or drop out of college without acquiring any academic qualification (Sithole et al., 2017). The major deterrents to student interest and success in STEM programs include multiple student-driven factors such as Mathematics proficiency, subject-specific study habits, time management, peer mentoring programs, student motivation, and self-efficacy. Current institutional practices that need improvement are academic advising, student course loads compared to credit hours, and pedagogical approaches. Other challenges involve enriching the STEM experience in high school curricula, out-of-field teaching in middle and high schools, along with ensuring the elimination of any discrimination based on gender, socio-economic status, or ethnicity. Persistence in STEM programs can be achieved by the provision of orientation programs, adoption of early warning systems, Mathematics review sessions, creation of student learning communities, professional development of faculty, as well as collaborative and outreach programs.

Creative ways of assessing student performances in higher education courses are being geared towards educators and instructional designers; for example, a peer-video-blog assessment that demonstrates the power and value of integrating peer- and video-assessments with social media/blogs (Luyegu & De, 2020). Digital learning platforms like Pearson Education and others have been conducting multiple online leadership forums with discipline-specific focus sessions to promote interpersonal communication among faculty across institutions for improving the content, delivery, and assessment of courses (De, 2020a).

Need for Cost-Effective Programs and Innovative Learning Platforms. Higher education institutions usually encounter the need to reduce the rising cost of hiring qualified instructors and serving more students as STEM programs are more expensive to run than other majors (Chirikov et al., 2020). Moreover, there is a need for innovating content, accessibility, and delivery platforms to address the needs of today's students. To offer affordable access to STEM education, some higher education institutions in different countries, including China, Russia, India, and the U.S., are offering STEM courses on national online education platforms. This has helped reduce the challenge of finding qualified STEM instructors and meet the rising demand for STEM careers (Chirikov et al., 2020). This model may be used by colleges and universities in the U.S. to meet the demands in the STEM field. This contemporary reality requires that higher education institutions embrace a more dynamic conceptualization of excellence in STEM education, one that advances innovation and correctly positions inclusion.

Several universities in the U.S. have been offering, at least, one STEM massive online open course (MOOC) to help students learn with affordability (Bonvillian & Singer, 2013). Universities offering this type, of course, need to make sure they abide by quality in the curriculum and instruction. Online features can be critical in STEM courses, especially when it comes to labs. Therefore, colleges and universities need to invest more in e-learning projects and develop and implement virtual labs to enhance the students' learning outcomes, especially nowadays with the transition to online learning due to the COVID-19 pandemic.

Lack of Funding for Interdisciplinary Research. Even before the COVID-19 crisis, higher education institutions in the U.S. were experiencing significant budget cuts. However, with the pandemic, some colleges and universities have had to even cut their budgets more to be able to survive. There is a need for more interdisciplinary research across the STEM disciplines. One way to help educational institutions support the faculty and students' interdisciplinary research projects is by searching for grants in the STEM area from various stakeholders, which may include: state and federal government agencies; private foundations, nongovernmental organizations, and professional societies (National Academies of Sciences & Medicine, 2018). Another way to build and enrich the interdisciplinary research in the STEM field is by improving current relationships and creating new connections between schools, higher education institutions, employers, and their communities (libraries, museums, and other resources). These strategic partnerships can help learners engage in research, internships, and apprenticeships and to blend curricula with active learning experiences (Education, 2018).

A composite summary of the main challenges recently reported to be facing the three key stakeholders in College STEM education – students, faculty, and higher education institutions, is outlined in Table 2.

Table 2
Summary of stakeholders' major, recently reported challenges in college STEM education

Students	Faculty	Higher Ed. Institutions
- Face-to-face and online challenges	- Lack of adequate professional development	- Student retention and attrition
- Active and experiential learning	- Challenge of teaching online and blended STEM courses	- Need for cost-effective programs and innovative learning platforms
- Real-world application of STEM concepts	- Shifting teaching practices	- Lack of funding for interdisciplinary research

Conclusions

STEM education prepares students for professional careers. Scientists and engineers create numerous innovations driving the global competitiveness of the United States of America. We need to understand and integrate key requirements of STEM education, incited strategies, along with endeavors of governments and private/public institutions. This article provides a comprehensive, three-way analysis of the state of STEM instruction from perspectives of essential college-level stakeholders (i.e., students, faculty, and organizations). Notable recent challenges/barriers facing these stakeholders, reported in the last decade, as well as potential solutions, are encapsulated. Researching this paradigm captures the challenges in traditional STEM education, possibly emphasizing the requirement for better investments in e-learning projects. Multifarious challenges face students, both in-person and online, along with a critical necessity for active learning and real-world application of STEM-based knowledge. Increased workload and new levels of uncertainty and stress prevail among faculty and higher education institutions. The new reality and rules require faculty leadership, to adopt a growth-oriented attitude. Also, the implementation of active learning principles and student-centered practices may allow educators to search for, develop, and present new strategies in the course design and pedagogical approaches. Faculty members ought to cultivate individual professional development skills, to advance their abilities to improve the educational culture and environment on behalf of students. Higher education institutions must encourage collaboration and shared objectives among STEM faculty members. The implementation of online learning platforms may help colleges and universities attract, engage, and retain learners. Furthermore, colleges and universities should continue seeking interdisciplinary and innovative research through public and private grants and by seeking community partnerships with various organizations and the community.

Competing Interest

The authors have no competing interests.

Authors' Contributions

Both authors contributed equally to the paper. Both the authors prepared, read and approved the final manuscript.

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