Paper ID #35105

Recent Strategies for improving Undergraduate Engineering Education: A Review

Ms. Monikka M. Mann, Texas Tech University

Monikka M. Mann, PMP is a PhD student at Texas Tech University in the Systems and Engineering Management Program.

Dr. George Tan, Texas Tech University

Session XXXX

Recent Strategies for improving Undergraduate Engineering Education: A Review

Monikka M. Mann, George Z. Tan
Industrial, Manufacturing, and Systems Engineering Department
Texas Tech University

Abstract

The need for highly trained and capable engineers to address increasingly complex problems that face society is clear. With the current pandemic, it is becoming increasingly imperative that Universities adjust their curricula and programs to prepare Engineering students with capabilities to overcome uncertainty. Multidisciplinary skills and the ability to communicate with disparate teams is a full-fledged requirement. This paper presents a review of six critical avenues for improving the quality and throughput of undergraduate engineering programs: 1) development of interdisciplinary undergraduate engineering curricula, 2) team-based engaged learning and research, 3) research-based teaching practices (RBTPs), 4) collaborations between academia and industry, 5) online/distance learning and telecommuting skills, and 6) the persistence of traditionally underrepresented students. In addition, future prospects of interdisciplinary project-based learning are discussed from three aspects: student competency, faculty development, and industry collaboration.

Introduction

The need for highly trained and capable engineers to address increasingly complex problems that face society is clear, less than 5% of the undergraduate degrees awarded in the US are in engineering, compared to 13% in European countries and nearly 25% in Asia [1]. It is becoming increasingly clear that universities in the United States must adapt their teaching and retention practices to adequately prepare students to fill critical roles in a technology focused, multi-disciplinary workplace [2]. The desire for a more interdisciplinary approach to undergraduate engineering education is evident as the transition to more geographically disparate teams is driving the need for engineering professionals to demonstrate that they possess not only the requisite technical acumen, but skills like communication, teamwork and conflict resolution that are not typically taught in the engineering classroom [3].

While the alarm has sounded for many years about a talent shortfall in the areas of STEM-related career, it is not evident that this is the case. While there may be a lack of expertise in certain specialist fields, there is little to no evidence that this shortage of STEM professionals is a widespread problem [4]. While some sources note that the United States will have over 1.2 million unfilled STEM jobs [5], there is really no consensus as to whether or not a panic is justified. Indeed, some conclude that the supposed STEM crisis is overblown and that the “problem” is ultimately imaginary [6].

In 2017, Deloitte and SEMI published the results of the Deloitte-SEMI Workforce Development

Survey. This study showed that 82% of employers surveyed felt that there was a shortage of qualified candidates in fields needed to fill critical roles in the semiconductor industry including electrical engineering, computer sciences, software engineering, mechanical engineering, systems engineering and materials science positions [7]. However, the idea of using employer estimations as conclusive data on may lead to faulty extrapolations where the experience they are describing is not an accurate representation of any such deficit on a nationwide level [4].

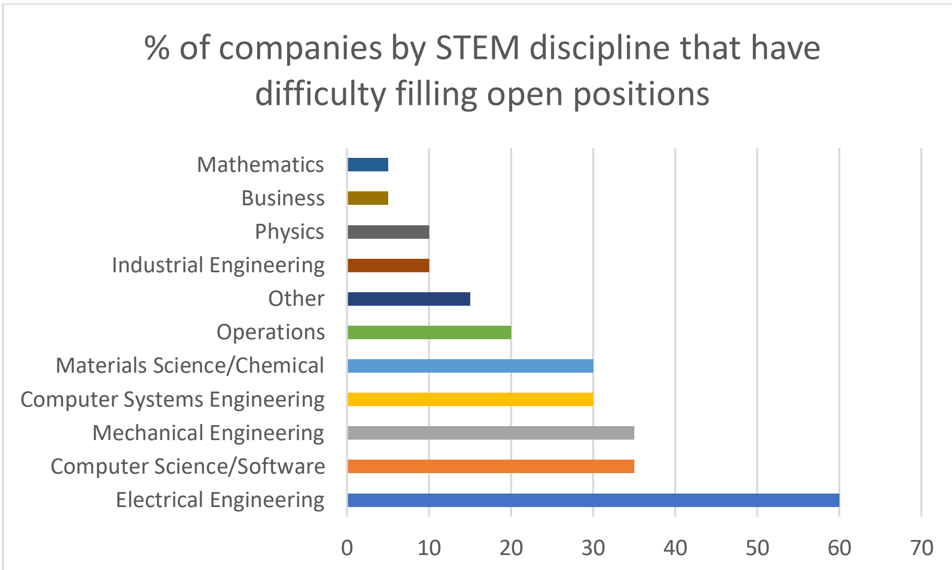

Figure 1 - Which Engineering Jobs are most difficult to fill? [4]

General Manufacturing is one area that is clearly experiencing a shortfall in the number of skilled employees to meet their needs. There will be a projected 2.4 million jobs that will be vacant in the US manufacturing industry due to a skills gap [8]. In summary, the only clear conclusion that can be drawn is this: both a surplus and crisis exists for STEM employees depending on the particular job market segment, so it is impossible to generalize a single answer to this question [9]. However, it is generally accepted that job-openings in STEM and STEM adjacent fields are expected to rise at an exponential rate in the next 10 years and, at present, there is a critical shortfall in the number of qualified and capable STEM professionals in the United states to meet this need [10, 11, 12, 13]. Specifically, for the semiconductor industry, four main themes were identified as their biggest challenges for attracting new talent and retaining existing skilled staff. These were "1) a shortage of students pursuing a STEM education; 2) lack of awareness of the industry and its vital importance in our everyday lives; 3) talent recruitment and retention issues partly because of the big, wildly popular consumer-facing companies; and 4) more restrictive immigration policies" [6].

Beyond the development of interdisciplinary curricula, there are other opportunities that may provide options to dramatically increase the quality and quantity of students who successfully finish an undergraduate engineering degree and ultimately enter the engineering workforce. Team-based learning supplements engineering education through its support of students improving their teamwork and communication skills. Developing "strong teamwork capabilities are highly required by employers in engineering sectors since engineering graduates are increasingly expected to work in team-based product and process design projects" [14]. Research-based teaching practices. (RBTPs) encompass a long list of instructional practices that have been shown through research to be effective in improving student achievement, engagement and persistence in STEM fields. These RBTPs include "the use of cooperative learning; problem-based learning; peer-led team learning; process-oriented, guided inquiry learning; and project-based learning over lecture-based teaching" [15]. Endeavors to find solutions to complex societal problems often require collaboration between industry and academia. This can be further formalized and integrated into the engineering classroom to provide new ideas for industry, incubate entrepreneurial interests in students, and provide a guaranteed pathway to an engineering career [16]. Lastly, there are unique challenges that face underrepresented minority (URM) students in completing their STEM education, particularly around "staying engaged in large lecture-style courses with limited opportunities for interaction with professors" [17]. Traditional, lecture-focused methods of engineering education have been shown to be largely ineffective at addressing the needs of the modern engineering student as we venture into the 21st Century; "existing teaching and learning strategies or culture in engineering programs is outdated and needs to become more student centered" [18].

There is no overlooking the impact that the COVID-19 pandemic has had on education over the past 12 months. Not only have schools at all levels been forced to adapt to new methods of instruction, students and teachers are being challenged to find new ways to learn now that many schools are forced to deliver this instruction remotely to either replace or augment traditional classroom lectures. It is estimated that nearly 70% of all students enrolled around the globe have been impacted by the disruptions associated with COVID-19 outbreaks [19]. The challenge that all stakeholders involved in Engineering Education must address – employers, institutions, faculty, and students alike – is to ensure that the quality of the education provided remains high while concurrently keeping students and staff safe. Engineering, as a field, relies heavily on hands-on, practical laboratory work. The benefits gained through these types of learning opportunities are not always easily replaced by virtual investigations [20], although great strides are being made in this area. The number of students successfully completing degrees in engineering studies is already of concern and serious thought should be given to discover ways to prevent the problem from becoming more widespread.

In this paper, a review was conducted to assess six possible avenues for improving the quality and throughput of undergraduate engineering programs. The six areas that will be discussed are the development of interdisciplinary undergraduate engineering curricula, team-based engaged learning and research, research-based teaching practices (RBTPs), collaborations between academia and industry, increasing availability of online/distance learning, and the persistence of traditionally underrepresented students. These topics were selected because of their novelty and potential impact to radically improve the experience of undergraduate engineering students which will hopefully lead to an increased number of students who successfully complete undergraduate engineering degrees.

Development of Interdisciplinary Undergraduate Engineering Curricula

Mounting evidence has shown that interdisciplinary work is becoming increasingly relevant to successful innovation activities. For example, Fleming [21], showed that teams made up of participants from varied backgrounds publish patents with a greater success rate than those that are homogenous. Some researchers argue that STEM education needs to be more interdisciplinary because the work environment is increasingly interdisciplinary or multidisciplinary regardless of whether the foundational educational environment taught this way [22, 23, 24]. Based on this, it is clear that "interdisciplinary connectors are critical to advancing innovation" [25]. Interdisciplinary education refers to the process when students are required to utilize the foundational knowledge from two or more disciplines in order to improve their successful comprehension of a problem beyond the state of knowledge that can be achieved by relying on just one discipline [26].

The primary way to implement an interdisciplinary approach [27] in the undergraduate engineering classroom is for faculty to present students with an instructional environment that allows them to explore connections between multiple disciplines through the use of scholarly discussions and a research driven problem-solving technique. Carmichael and LaPierre have shown that students who participate in an interdisciplinary curriculum, have nearly a quarter point higher grade point average than students who chose a more traditional educational path [28].

Team-Based Engaged Learning and Research

The benefits of team-based engaged learning and research are also supported by Research Based Teaching Practices that are discussed in more detail in the next section. Team-based learning, or Cooperative learning, is the learning which occurs when students are structured into "groups with defined roles for each student and a task for the group to accomplish" [29]; it is typically exhibited when teachers encourage the "instructional use of small groups so that students work together to maximize their own and each other's learning" [30]. Positive cognitive results, increased student academic achievement, and more positive student attitudes towards learning were observed in classrooms where cooperative learning opportunities were encouraged [31]. There is near universal accord that cooperative learning methods "can and usually do have a positive effect on student achievement" [32].

Social Learning Theory, or SLT, emphasizes learning that occurs in a social context [29]. SLT describes the process whereby students learn by observing and interacting with their peers. In the traditional classroom, this learning typically occurs face to face only with the students in the classroom, school or local community. Due to the strong correlation between SLT and peer influence, it stands to reason that, with proper controls in place, teachers can shape and observe these interactions to have a positive learning outcome for the students; one study at Duke University found that collaborative learning led to higher levels of student engagement, self-efficacy and desire to complete a STEM major while lowering the sense of competition among the students [33]. This means that cooperative learning can encourage student academic performance during instructional activities. This means that cooperative learning can encourage student academic performance during instructional activities. In addition to self-efficacy, collaborative learning has positive impacts on student knowledge building and ultimately (possibly most importantly) improved course grades [34]. This study, conducted on a group of 513 students, 16% of whom were female, showed through the use of multivariate analysis that exposure to collaborative learning strategies strongly correlated ($p < 0.1$) to increase self-efficacy among this population of engineering students.

Ideally, students will be encouraged to develop their own small learning communities of their peers in class for acquiring knowledge in the Differentiated classroom. These small learning communities will only be meaningful if the participants are fully engaged in the process, i.e., if they are fully present in their interactions [35]. This quality of being fully engaged partners in communication is defined as social presence and the absence of this social presence can have a negative impact on social learning. Rather than focusing purely on lecturing and rote memorization, social interaction during a STEM activity can be an effective way for students to learn and retain information versus a traditional lecture-based instructional method. In addition, these social interactions encourage the development of soft skills such as conflict resolution, time management, and communication which are equally as important as technical knowledge when entering the modern workforce.

One way of incorporating SLT and cooperative learning in the engineering classroom is through the implementation of Problem Based Learning (PBL) or Project Based Learning (PjBL) and utilization of these techniques in the classroom is most successful when students are assessed on concepts that require the application of knowledge developed through long-term retention of data [36]. In an ideal cooperative learning classroom, students will work in small groups, or teams, to incorporate social aspects to the learning process by collectively generating questions and authentic solutions to the problem being solved [37]. To ensure that students are on track with meeting the required learning objectives, the quality of the small group interactions is important, and the instructor must be cognizant of how to address potential dysfunctions to ensure that all students are not only present but that their presence is in alignment with appropriate social etiquette and communication skills.

In addition, another area where cooperative learning is especially impactful is in the development of employability skills. Employability skills refer to those basic skills that are necessary for an individual to obtain, maintain, and succeed in meaningful employment. Students expect to leave school after having gained the skills, knowledge and ability to earn a job [38]. These skills include not only basic academic skills but higher-level thinking skills and the so-called “soft skills” such as time management, communication, punctuality and cooperation [39].

Research Based Teaching Practices (RBTPs)

As briefly discussed earlier, Research Based Teaching Practices (RBTPs) are teaching practices that have been shown to be effective in improving student learning, engagement, and ultimately persistence in the STEM classroom. The ultimate goal is to of implement instructional changes based on models of “how students learn and the types of expertise and skills that will best serve students in their future careers” [40] . Kipper and Rüütmann [41], propose that when teaching engineering subjects, if an instructor is able to utilize instructional techniques focused on developing deeper understanding and critical thinking skills, their students will be able to better engage and apply the knowledge being taught. The skills described by Kipper and Rüütmann align closely with Bloom’s Taxonomy of learning. “Taxonomies are devices that classify and show relationships among things” [42] and Bloom’s taxonomy for educational objectives has been used since the 1950s to “provide a framework for classifying learning objectives and a way for assessing them” [42]. By promoting deeper understanding and critical thinking skills among their students, engineering educators are moving their students from the basics of remembering and applying factual knowledge to the ultimate state of metacognition, or when students gain awareness of themselves as problem solvers and therefore have an innate sense of confidence in their ability to tackle obstacles without relying on others for assistance or guidance [43]. Using proven RBTPs is one way to prepare the STEM workforce of the future and to provide companies, and our country, with STEM professionals that are equipped with not just rote learning but new ways of applying their existing knowledge to more novel and complex problems.

One proposed RBTP is a pedagogical approach called Scientific Teaching (ST). Implementation of ST requires that professors modify their classroom instruction to include more active learning techniques so that students are more engaged and develop improved scientific reasoning skills [44, 45]. There are three key elements of ST: active learning, assessment, and inclusivity [46] and if undergraduate engineering education incorporated ST into regular pedagogical practice, there is an opportunity to address several of the aforementioned improvement opportunities along with developing the key skills that employers want in the future STEM workforce. The implementation of ST requires complex human behaviors that include and are modified by social interactions between instructors and students, engaging classroom environments, and authentic performance tasks that consider not only the content under student but the cognitive skills needed to successfully achieve a given learning objective [47].

Another RBTP, Project Based Learning (PjBL), encourages increased student engagement in situations where they need to solve problems [48] through the use of real-life problems. In order for Project Based Learning to be effective, there are five criteria that must be incorporated into its implementation in the Engineering Classroom: the project selected must be relevant to the subject area, the problem solved should focus on problems that present a challenge to the students, students are active participants in the investigation of solutions, students lead the discussion and the problem must be realistic or solvable [49]. Project Based Learning can include Cooperative Learning; one example of this in a secondary classroom shows clear roles for each student team member and a rubric that is provided to the students that unambiguously defines the problem that students are being asked to solve related to finding a new solution to problem that was previously provided to the students and this problem encouraged the students to utilize skills in “critical thinking, problem solving, collaboration and various forms of communication” [50] and was based on what students were currently learning not only in their STEM class but their Social Studies class ; meaning the project was cross-disciplinary in nature as well.

Collaborations between Academia and Industry

For many students, particularly those who choose not to progress beyond an undergraduate degree, the ultimate goal of education is to obtain a good paying job in industry. Indeed, data from the Bureau of Labor Statistics shows that students with a bachelor’s degree have a lower unemployment rate (2.2%) and higher median weekly earnings ($1497) than students with less education (an average of 3.78% unemployment rate and $765/week) [51]. Additional data shows that Management, Scientific, and technical consulting services, with a projected growth of 334,200 jobs from 2019 to 2029, make up many of the top fastest growing areas for wage and salary employment, or number of jobs [52]. Because of this desire to enter the industrial workforce post-graduation, it would only be logical to have industry representation in the development of academic curricula so that the entering staff are well trained and able to make meaningful contributions to their employer soon after starting the employment.

In addition to a well-qualified workforce, increasing industry involvement with education has provided a source of funding for universities and a low-cost supply of early-stage research for companies [53]. Another benefit of this is that many universities are acting as key partners with local industries which provides a direct pipeline of trained, already indoctrinated entry-level employees.

Online/Distance Learning

The response to continuing education in the midst of a pandemic in the United States has leaned heavily on online learning at all grade levels. Distance learning is not a new fad, and in fact, has existed in some form for over a century [54]. Online learning is generally accepted to have started in the 1980s [55]. Distance learning typically refers to "providing access to learning for those who are geographically distant" [56] from the instructor who is typically located in a different place from the learner and it can also include asynchronous learning. Online learning is sometimes used interchangeably with distance learning, but it should really be considered as a more recent, and much improved, incarnation of distance learning that is especially suited to improve "access to educational opportunities for learners described as both nontraditional and disenfranchised" [56]. One of the primary features of online learning is that the learning is accomplished via the use of technology and this learning is characterized by its connectivity, temporal flexibility and the ability to encourage varied interactions between learners and the instructor. In this new era of social distancing, online learning is allowing students of all ages to remain on track with their educational progress while staying socially distant and reducing the spread of COVID-19.

Laboratory investigations are important to student learning in that they provide students with the opportunity to interact directly with the tools, data, theories and models involved with conducting science. Advances have been made towards replicating the ability of online learners to complete laboratory experiments that traditionally are conducted in-person. Virtual laboratories, where students can conduct experiments online to explore engineering concepts and theories without physically stepping into a lab, provide opportunities for students to access scientific knowledge regardless of their ability to access equipment and facilities. Research has shown that there is virtually no difference in student ability to acquire knowledge of scientific concepts though the use of a virtual laboratory explorations versus being physically present to conduct an experiment [57]. Offered online, virtual laboratories add value to classroom instruction by allowing students to observe phenomena that may not be apparent during physical experiments in order to link observable and unobservable phenomena, focusing on salient information, providing access to the knowledge gained from conducting an experiment without needing to worry about material availability or setup, minimizing the contact with hazardous materials, providing the ability to complete experiments from their home, and they can offer individualized, adaptive guidance [20].

Many detractors find fault with online learning delivery and believe that it will not meet the same standards of quality found in traditional engineering classrooms. However, as is shown above, engineering education as usual is not meeting the needs of students, employers, or society. Transitioning to online education is going to be vital for the continued existence of colleges and universities due to the projected increases in off-campus and nontraditional students [58] which have now been exacerbated due to social distancing driven by the pandemic. Again, the need to work with students at a distance and those for whom traditional education is not a fit is apparent as is the need to improve online learning rather than tearing it down. When asked about various pedagogical practices that should be used more widely in online education, a large number (over 65%) of respondents said that team-based problem solving and collaborative tasks was their top choice, followed closely by problem-based learning at 58.1% [59]. Both pedagogical techniques have been discussed previously in this article as crucial for increasing the number of students entering the STEM pipeline.

Persistence of Traditionally Underrepresented Students

Researchers believe that there is a shortage of well-qualified, US workers in the United States to fill STEM jobs. H-1B Visa holders traditionally compensated for this shortfall but due to recent changes in the economic climate in the US, this supply line could dwindle soon as foreign workers may prefer to work in their native countries given the anti-immigrant rhetoric in the country. If these foreign workers and researchers do leave the United States, or don't come in the numbers they've done historically, there is a very real chance that American technical innovation will substantially decrease [25]. Given that the percentage of White, non-Hispanic males – traditionally the largest component of the STEM workforce – continues to shrink from 70% in 1997 to possibly less than 30% of the workforce by 2050 [60], it only makes sense that to keep the same level of innovation in the global economy, other segments of the US population must be supported and encouraged to fill these critical STEM positions. Underrepresented Minorities (URM) are a resource that is vital to provide a source for the next generation of workers able to fill these key technical roles. Efforts to increase diversity in STEM have been tried for nearly 25 years but URM, "representation in STEM still lags far behind that of White, non-Hispanic men" [61]. As of 1997, White males made up 67.9% of the US STEM Workforce, while only 3.2% of the STEM workforce in the United States identified as African Americans, both male and female [62].

Increased access to online learning could be a vital step to keeping traditionally underrepresented students engaged with, and succeeding in, their STEM Classes. Online learning can improve access to education experiences for traditionally underrepresented students that are challenged by the barriers of cost, location, and the need to fit education into a schedule already dedicated to existing work or family obligations. It has been shown that "online learning … has the potential to increase the access and progression of the traditionally underrepresented groups in science, engineering, technology, and mathematics (STEM) disciplines" [63]. Researchers looking into the "impact of STEM faculty teaching and mentoring on students' persistence and STEM degree attainment" [61] may be well-served by looking at new pedagogies and instructional delivery methods.

Summary and Conclusions

This paper discussed six critical areas for continuous improvement of STEM undergraduate education in the United States: 1) development of interdisciplinary undergraduate engineering curricula, 2) team-based engaged learning and research, 3) research-based teaching practices (RBTPs), 4) collaborations between academia and industry, 5) online/distance learning and telecommuting skills, and 6) the persistence of traditionally underrepresented students The ability to merge characteristics from each of the six identified areas into one cohesive undergraduate engineering curricula may be challenging to implement right away but some components, particularly online learning approaches, have already seen widespread use due to the ongoing COVID-19 pandemic. Great strides have been made in some of these areas but without adequate faculty training in these methods, substantive change will not occur.

The use of online education – combined with RBTPs, team-based collaborative efforts, interdisciplinary approaches to instruction, and support from industrial partners – may be a transformative approach that improves the quality of education provided, broadens participation in STEM, and lays the groundwork for institutional improvement. Implementation of these 5 improvements to pedagogy has the potential to drive advancements in the persistence of traditionally underrepresented students as well as mainstream, traditional learners. Future work in this area will include the development of a course to test hypotheses around the benefits of integrating RBTPs and team-based, collaborative learning into an undergraduate engineering course to measure the efficacy of these approaches in terms of positive student learning outcomes and attitudes towards pursuing further engineering education.

References

[1] National Academy of Engineering, "The Importance of Engineering Talent to the Propserity and Security of the Nation: Summary of a Forum," National Academies Press, Washington, D.C., 2014.

[2] M. C. Thursby, "The Importance of Engineering: Education, Employment, and Innovation," *The Bridge*, vol. 44, no. 3, pp. 5-10, 2014.

[3] National Academy of Engineering, "Understanding the Educational and Career Pathways of Engineers," National Academies Press, Washington, D.C., 2018.

[4] E. Smith, "Shortage or surplus? A long-term perspective on the supply of scientists and engineers in the USA and the UK," *Review of Education*, vol. 5, no. 2, pp. 171-199, 2017.

[5] Elsevier, "10 Major Engineering Challenges of the Next Decade," [Online]. Available: https://www.elsevier.com/rd-solutions/industry-insights/other/10-major-engineering-challenges-of-the-next-decade. [Accessed March 2020].

[6] M. Lapedus, "Engineering Talent Shortage Now Top Risk Factor," 25 February 2019. [Online]. Available: https://semiengineering.com/engineering-talent-shortage-now-top-risk-factor. [Accessed 29 February 2020].

[7] C. Richard, K. Ramachandran and I. Pandoy, "Looming Talent Gap Challenges Semiconductor Industry," 2018. [Online]. Available: https://www.semi.org/en/workforce-development/diversity-programs/deloitte-study. [Accessed 5 March 2020].

[8] Deloitte Insights, "2018 Deloitte and The Manufacturing Institute skills gap and future of work study," 2018. [Online]. Available: https://www.themanufacturinginstitute.org/research/2018-

deloitte-and-the-manufacturing-institute-skills-gap-and-future-of-work-study/. [Accessed 15 March 2020].

[9] Y. Xue and R. C. Larson, "STEM crisis or STEM surplus? Yes and yes," May 2015. [Online]. Available: https://www.bls.gov/opub/mlr/2015/article/stem-crisis-or-stem-surplus-yes-and-yes.htm.

[10] E. Babco, "Skills for the innovation economy: What the 21st Century workforce needs and how to provide it," Commission on Professionals in Science and Technology, Washington, D. C., 2004.

[11] N. Terrell, "STEM Occupations: High-tech jobs for a high-tech economy," *Occupational Outlook Quarterly,* vol. 51, no. 1, pp. 26-33, 2007.

[12] M. Lufkin, "The STEM equity pipeline," in *North Carolina College Career Tech Prep Conference,* Greensboro, NC, 2008.

[13] National Science Foundation, "Broadening participation in America's Science and Engineering Workforce: The 1994-2003 decennial and 2004 biennial reports to Congress," Arlington, VA, 2004.

[14] V. Najdanovic-Visak, "Team-based learning for first year engineering students," *Education for Chemical Engineers,* vol. 18, pp. 26-34, 2017.

[15] C. J. Finelli and J. E. Froyd, "Improving Student Learning in Undergraduate Engineering Education by Improving Teaching and Assessment," American Society for Engineering Education, 2019.

[16] C. Arlett, F. Lamb, R. Dales, L. Willis and E. Hurdle, "Meeting the needs of industry: the drivers for change in engineering education," *Engineering Education,* vol. 5, no. 2, pp. 18-25, 2010.

[17] B. Toven-Lindsey, M. Levis-Fitzgerald, P. H. Barber and T. Hasson, "Increasing persistence in undergraduate science majors: A model for institutional support of underrepresented students," *CBE—Life Sciences Education,* vol. 14, no. 2, pp. 1-12, 2015.

[18] J. E. Mills and D. F. Treagust, "Engineering education—Is problem-based or project-based learning the answer.," *Australasian journal of engineering education,* vol. 3, no. 2, pp. 2-16, 2003.

[19] J. Qadir and A. Al-Fuqaha, "A Student Primer on How to Thrive in Engineering Education during and beyond COVID-19," *Education Sciences,* vol. 10, no. 9, pp. 236-257, 2020.

[20] T. De Jong, M. Linn and Z. Zacharia, "Physical and Virtual Laboratories in Science and Engineering Education," *Science,* vol. 340, no. 6130, pp. 305-308, 2013.

[21] L. Fleming, "Perfecting Cross-Pollination," *Harvard Business Review,* pp. 22-24, September 2004.

[22] E. G. Derrick, H. J. Falk-Krzesinski, M. R. Roberts and S. Olson, "Facilitating interdisciplinary research and education: A practical guide," Science on FIRE: Facilitating Interdisciplinary Research and Education" workshop of the American Association for the Advancement of Science, 2011.

[23] Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century National Research Council, "BIO2010: Transforming Undergraduate Education for Future Research Biologists," National Academies Press, 2003.

[24] National Research Council, "Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics," National Academies Press, 2003.

[25] R. D. Atkinson and M. Mayo, "Refueling the US innovation economy: Fresh approaches to science, technology, engineering and mathematics (STEM) education," The Information Technology & Innovation Foundation, 2010.

[26] M. N. Mahmud, "Interdisciplinary Learning in Engineering Practice: An Exploratory Multi-case Study of Engineering for the Life Sciences Projects," University of Cambridge, October 2017. [Online]. Available: https://www.repository.cam.ac.uk/bitstream/handle/1810/277441/Mahmud-2018-PhD.pdf?sequence=1. [Accessed 22 January 2021].

[27] K. Holley, "Interdisciplinary curriculum and learning in higher education," in *Oxford research encyclopedia of education*, B. Lingard, S. Sellar, S. Lewis and G. W. Noblit, Eds., 2017.

[28] T. Carmichael and Y. LaPierre, "Interdisciplinary learning works: The results of a comprehensive assessment of students and student learning outcomes in an integrative learning community," *Issues in Interdisciplinary Studies,* vol. 32, pp. 53-78, 2014.

[29] M. W. Keyser, "Keyser, M. W. (2000). Active learning and cooperative learning: understanding the difference and using both styles effectively," *Research Strategies,* vol. 17, no. 1, pp. 35-44, 2000.

[30] D. W. Johnson and R. T. Johnson, "An Overview of Cooperative Learning," [Online]. Available: http://www.co-operation.org/what-is-cooperative-learning. [Accessed 15 May 2020].

[31] R. Lazarowitz and R. Hertz-Lazarowitz, "Cooperative learning in the science curriculum," in *International handbook of science education*, B. J. Fraser and K. G. Tobin, Eds., London, Kluwer Academic Publishers, 1998, pp. 449-469.

[32] R. E. Slavin, "Research on cooperative learning: Consensus and controversy," *Educational Leadership,* vol. 47, no. 4, pp. 52-54, 1988.

[33] N. Santerio, T. Braswell, M. Long, C. Shead, B. Their, J. Yu, T. Newpher and M. Ng, "Collaborative Learning in STEM Postively Impacts Student Outcomews," 2020. [Online]. Available: https://bassconnections.duke.edu/sites/bassconnections.duke.edu/files/site-images/22-collaborative-learning-stem.pdf. [Accessed 21 January 2021].

[34] G. S. Stump, J. C. Hilpert, J. Husman, W. T. Chung and W. Kim, "Collaborative learning in engineering students: Gender and achievement.," *Journal of engineering education,* vol. 100, no. 3, pp. 475-497, 2011.

[35] C. Tu, "On-line learning migration: From social learning theory to social presence theory in a CMC environment," *Journal of Network and Computer Applications,* pp. 27-37, 2000.

[36] A. Oguz-unver and S. Arabacıoğlu, "A comparison of inquiry-based learning (IBL), problem-based learning (PBL) and project-based learning (PjBL) in science education," *Academia Journal of Educational Research,* pp. 120-128, 2014.

[37] W. Hung, "Theory to Reality: A Few Issues in Implementing Problem-Based Learning," *Educational Technology Research and Development,* pp. 529-552, 2011.

[38] S. Rosenberg, R. Heimler and E. Morote, "Basic employability skills: A triangular design approach," *Education & Training,* vol. 54, no. 1, pp. 7-20, 2012.

[39] G. W. Mitchell, L. B. Skinner and B. J. White, "Essential Soft Skills for Success in the Twenty-First Century Workforce as Perceived by Business Educators," *Delta Pi Epsilon Journal,* vol. 52, no. 1, 2010.

[40] M. F. Durham, J. K. Knight and B. A. Couch, "Measurement Instrument for Scientific Teaching (MIST): a tool to measure the frequencies of research-based teaching practices in undergraduate science courses," *CBE—Life Sciences Education,* vol. 16, no. 4, pp. 1-14, 1 December 2017.

[41] H. Kipper and T. Rüütmann, "Teaching for understanding in engineering education," in *2012 15th International Conference on Interactive Collaborative Learning (ICL)*, 2012.

[42] R. I. Arends, Learning to teach, Tenth ed., New York, NY: McGraw Hill Education, 2012.

[43] S. Y. McGuire, Teach students how to learn: Strategies you can incorporate into any course to improve student metacognition, study skills, and motivation, Sterling, VA: Stylus Publishing, LLC, 2015.

[44] S. Miller, C. Pfund, C. M. Pribbenow and J. Handelsman, "Scientific teaching in practice," *Science,* vol. 322, no. 5906, pp. 1329-1330, 2008.

[45] J. Handelsman, D. Ebert-May, R. Beichner, P. Bruns, A. Chang, R. DeHaan, J. Gentile, S. Lauffer, J. Stewart, S. M. Tilghman and W. B. Wood, "Scientific teaching," *Science,* vol. 204, no. 5670, pp. 521-522, 2004.

[46] B. A. Couch, T. L. Brown, T. J. Schelpat, M. J. Graham and J. K. Knight, "Scientific teaching: Defining a taxonomy of observable practices," *CBE—Life Sciences Education,* vol. 14, no. 1, pp. 1-12, 2015.

[47] M. T. Hora and J. J. Ferrare, "Instructional systems of practice: A multidimensional analysis of math and science undergraduate course planning and classroom teaching.," *Journal of the Learning Sciences,,* vol. 22, no. 2, pp. 212-257, 2013.

[48] Y. Doppelt, "Implementation and assessment of project-based learning in a flexible environment," *International Journal of Technology and Design Education,* vol. 13, pp. 255-272, 2003.

[49] S. R. Tamim and M. M. Grant, "Definitions and Uses: Case Study of Teachers Implementing PjBL," *The Interdisciplinary Journal of Problem-based Learning,* vol. 7, no. 2, pp. 72-101, 2013.

[50] D. G. Prier, M. M. Mann, H. M. Oluseyi and R. Hite, "Life Skills Students in the STEM Classroom: Robotics as Effective Project Based Learning," *Technology and Engineering Teacher,* vol. 77, no. 9, pp. 1-7, November 2018.

[51] U.S. Bureau of Labor Statistics, "Employment Projections," 4 September 2019. [Online]. Available: https://www.bls.gov/emp/chart-unemployment-earnings-education.htm.

[52] U.S. Bureau of Labor Statistics, "Employment Projections," 1 September 2020. [Online]. Available: https://www.bls.gov/emp/tables/industries-fast-grow-decline-employment.htm.

[53] K. R. Lutchen, "Why Companies and Universities Should Forge Long-Term Collaborations," *Harvard Business Review,* vol. 24, 24 January 2018.

[54] J. M. Spector, M. D. Merrill, J. Elen and M. J. Bishop, Eds., Handbook of research on educational communications and technology, Spring Science & Business Media, 2013.

[55] L. Harasim, "Shift happens: Online education as a new paradigm in learning," *The Internet and Higher Education,* vol. 3, no. 1-2, pp. 41-61, 2000.

[56] J. L. Moore, C. Dickson-Deane and K. Galyen, "E-Learning, online learning, and distance learning environments: Are they the same?," *The Internet and Higher Education,* vol. 14, no. 2, pp. 129-135, 2011.

[57] Z. C. Zacharia and C. P. Constantinou, "Comparing the influence of physical and virtual manipulatives in the context of the Physics by Inquiry curriculum: The case of undergraduate students' conceptual understanding of heat and temperature," *American Journal of Physics,* vol. 76, no. 4, pp. 425-430, 2008.

[58] D. L. Carl, "Electronic distance learning: Positives outweigh negatives," *THE Journal (Technological Horizons in Education),* vol. 18, no. 10, 1991.

[59] K. J. Kim and C. J. Bonk, "The future of online teaching and learning in higher education," *Kim, Kyong-Jee, and Curtis J. Bonk. "The future of online teaching and learning in higher education." Educause quarterly,* vol. 29, no. 4, pp. 22-30, 2006.

[60] J. Day, "Population projectsion of the United States by age, sex, race and Hispanic origin: 1995 to 2050," U.S. Census Bureau, Arlington, VA, 1996.

[61] Y. S. George, D. S. Neale, V. Van Horne and S. M. Malcolm, "In pursuit of a diverse science, technology, engineering, and mathematics workforce.," American Association for the Advancement of Science, 2001.

[62] Conmission on the Advancement of Women and Minorities in Science, Engineering, and Technology Development, "Land of Plenty: Diversity as America's competitive edge in science, engineering, and technology," National Science Foundation, Arlington, VA, 2000.

[63] C. Wladis, K. M. Conway and A. C. Hachey, "The Online STEM Classroom—Who Succeeds? An Exploration of the Impact of Ethnicity, Gender, and Non-traditional Student Characteristics in the Community College Context," *Community College Review,* vol. 43, no. 2, pp. 142-164, 2015.