Active Learning in Undergraduate STEM Education: A Review of Research

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Introduction

Traditionally, the college classroom has been a place where professors lecture and students are expected to listen and learn with little to no participation. However, there has been a movement toward transforming the college classroom to foster dynamic student centered learning. This shift is particularly significant for college students in pursuit of science, technology, engineering, and mathematics (STEM) degrees since the ability to apply the knowledge and theory learned in the classroom is important to success in their future careers.

In recent years, there has been increasingly more focus on STEM education from a national perspective (Gasiewski, Eagan, Garcia, Hurtado, & Chang, 2012). Consequently, it is important for our youth to be equipped with the knowledge and skills to solve challenging problems, gather and evaluate information, and interpret data. These types of skills are acquired by studying science, technology, engineering, and mathematics, subjects collectively known as STEM (U.S. Department of Education, 2015). However, the number of students who pursue, persist, and complete degrees in STEM is low. In fact, based on national college and university statistics, only about 40% of students who plan to complete a degree in a STEM area actually do so (President's Council of Advisors on Science and Technology, 2012). As a result, nationally there is a lack of STEM professionals, which leaves us with less talent available to be innovators of science and technology.

When students are taught to think deeply, they have opportunities to become the future innovators, educators, researchers, and leaders in our country and the world. But, according to a recent report by the U.S. Department of Education, not enough of our youth have access to quality STEM learning opportunities and too few students see these disciplines as potential career paths. For example: 81% of Asian-American high school students and 71% of white high school students attend high schools where a full range of STEM courses are offered. However, the access to this type of education is limited for American Indian, Native-Alaskan, Black, and Hispanic high school students

(U.S. Department of Education, 2015). Since many students do not have access to a variety of science and mathematics courses in kindergarten through twelfth grades, when they enter college they are not necessarily college ready or prepared to thrive in college level STEM education. Therefore, it is critical to improve k-12 education and to implement instructional strategies at the collegiate level to enhance the learning and educational opportunities of every student, including those from underrepresented groups in order to prepare them for a modern STEM economy.

Minority serving institutions (MSIs), like Hispanic Serving Institutions (HSIs) and Historically Black Colleges and Universities (HBCUs) are very important in training the next generation of scientists, particularly those who are from underrepresented groups. Specifically, HBCUs are positioned to meet the STEM challenge as “engines of economic growth and ladders of advancement for generations of African Americans” (U.S. Department of Education, 2016). In fact, for more than a century, HBCUs have been frontrunners in educating African-American college graduates who excel in their fields. Even though our nation’s HBCUs make up only 3% of the colleges and universities, they produce 27% of African-American students with bachelor’s degrees in STEM fields (U.S. Department of Education, 2016).

In 2012 the President’s Council of Advisors on Science and Technology developed a report on the state of STEM in America entitled, “Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics”. Overall, this article emphasized the importance of increasing the number of graduates in STEM areas in order to maintain scientific preeminence in the United States of America. This report specifies challenges that must be addressed in our college and university classrooms. Three recommendations were highlighted in the report: improve the first two years of STEM education in colleges/universities, provide all students with the tools and resources they need to excel, and diversify pathways to STEM degrees (President’s Council of Advisors on Science and Technology, 2012).

It is a known fact that sometimes the course content in STEM classes is challenging, but the learning environment can have a major impact on student interest and motivation. As a result, many students leave STEM disciplines before they can realize their potentials (Petrillo, 2016). Studies have shown that teaching techniques that engage students as active participants improve retention of information and critical thinking skills and can greatly increase STEM major interest and persistence, compared with traditional lecture (President’s Council of Advisors on Science and Technology, 2012).

Figure 1 highlights some of the major factors that impact student success in STEM courses at the collegiate level. As indicated in Figure 1, there are several factors that influence student overall performance and success in college level STEM courses.

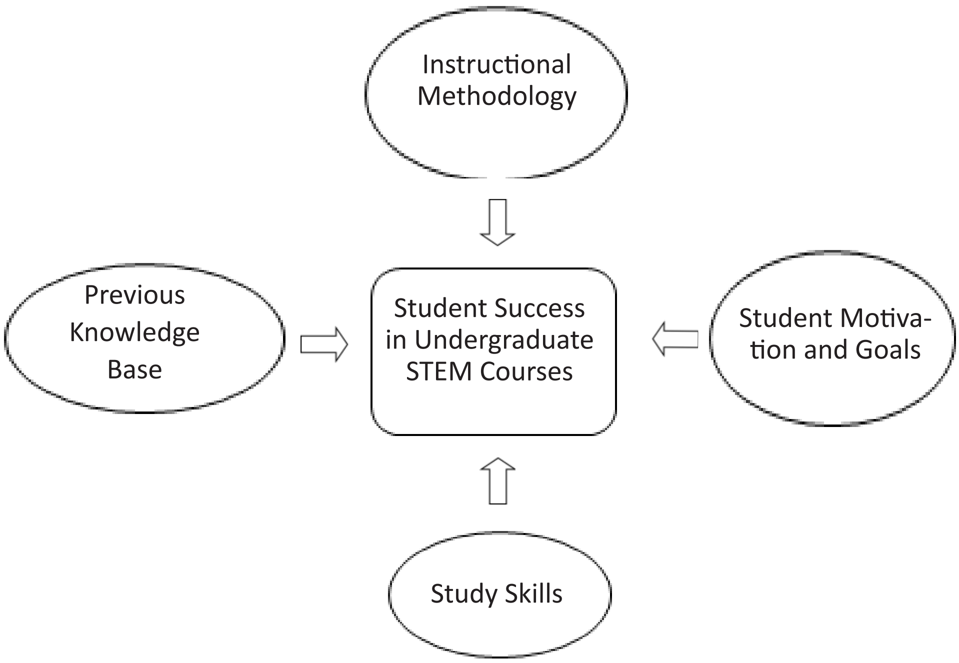

Figure 1. Major Factors Impacting Student Success in Undergraduate STEM Courses

The teaching methodologies utilized by professors can also have a positive impact on the other major factors that influence student academic success in STEM. The focus of this paper is the instructional methodology implemented by the professor, specifically active learning techniques.

Despite what the research has shown about the positive effects of student engagement on student learning, lecture remains the primary method of instruction in college classrooms. This style of teaching is referred to as "teaching by telling" because it involves an instructor centered approach (Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt, & Wenderoth, 2014). This technique requires little to no participation by the student during class time. As a result, the professor does not receive immediate feedback about the student knowledge base or his/her level of understanding of the course material. In addition, traditional lecture often fails to encourage intellectual engagement which is an important hallmark of college education (Smith, Sheppard, Johnson, & Johnson, 2005). Therefore, lecture with minimal student participation may have the unintended consequences of stifling a student's progress and diminishing a student's confidence in his/her ability. While lecture is still an important component of classroom instruction, it should be supported by student centered instructional strategies.

Classroom environments in which students are given opportunities to participate in science and mathematical investigation, communication, and group problem-solving, and simultaneously receiving feedback on their work from both professors and peers, have a positive effect on learning (Conference Board of the Mathematical Sciences, 2016). Teaching techniques that include these types of activities are called active learning methods. Based on a variety of studies, these methods have been shown to strengthen student comprehension and performance in STEM courses, to enhance students' confidence in their ability to do science and mathematics, and to increase the diversity of the STEM community (Conference Board of the Mathematical Sciences, 2016).

One way to improve the first two years of college STEM education is through enhanced instructional strategies, which actively include the student in the learning process. As a result, some college professors have developed and utilized more teaching strategies which engage students in the learning process. One prominent methodology is active learning.

The term "active learning" as it is currently interpreted dates to the early 1990s and the work of Bonwell & Eison (1991), building on the work of Revans (1983) (Conference Board of the Mathematical Sciences, 2016). Researchers have investigated the relative effectiveness of various classroom strategies that complement other elements of effective teaching. These include the following: well-designed courses with goals and learning outcomes clearly communicated to students, allowing students to learn new material and make connections with previous knowledge, and giving students timely feedback about their work and thinking related to the course content (Fink, 2013).

In this paper, we examine the literature that considers active learning in STEM education. We do this in three main sections, aiming to: (a) define some of the major active learning teaching techniques; (b) highlight key STEM active learning studies conducted; and (c) discuss the impact of active learning in STEM education on diverse student populations.

Definitions

In recent years, there have been many studies supporting a move toward active learning in college classrooms, particularly in STEM education. Active learning is a broad term that encompasses several models of instruction, including cooperative and collaborative learning, problem based learning, inquiry based learning, discovery learning, and experiential learning (Barkley, 2010). It is a process of education whereby students engage in activities, like reading, writing, discussion, or problem-solving that encourage analysis, synthesis, reflection and evaluation of class content. Active learning techniques have been shown to improve student retention of information while critical thinking skills, which result in an increase in STEM major interest and persistence compared to traditional lecture based instruction. Overall student engagement typically increases the success rate of students in college classrooms. We highlight some of the strategies used when active learning techniques are implemented into a course.

Cooperative learning is also called peer-team learning and it benefits students in several ways. This teaching technique involves structuring classes around small groups of students that work together to pursue common goals while being assessed individually (Prince, 2004). Cooperative learning should: (i) provide students with a supportive environment where they can asks questions, (ii) engage students in discussions that will help them understand important concepts, (iii) encourage students to participate in teamwork which will benefit them in the future, (iv) allow students to develop better communication skills, and (v) support peer leaders in gaining important teaching and leadership skills in a safe environment.

Problem based learning (PBL) is a student centered instructional approach that empowers students to conduct research, combine theory and practice, and apply knowledge and skills to develop a viable solution to a well-defined problem (Savery, 2015). This approach is most successful when the problems selected are interdisciplinary yet not well structured and the professor guides the learners through the process and gives a thorough summary at the end of the learning experience. It is an instructional method where relevant problems can be introduced at the beginning of the lesson and used to provide the context and motivation for the learning that follows (Prince, 2004). This type of learning may be extremely beneficial for a student majoring in STEM, especially engineering, because it helps them make the connection between the theory learned in class and the practice/application of those skills on real-life problems. Students who engage in PBL usually acquire skills, such as the following, the ability: (i) to think deeply and critically, (ii) to analyze and solve multipart problems, (iii) to work cooperatively, (iv) to effectively communicate their knowledge, and (v) the skill of maximally utilizing the resources available.

One prominent method used across STEM disciplines is inquiry based learning (IBL). IBL includes a range of educational methods that allow the student to demonstrate curiosity and answer questions through an active process of exploration. This technique can be utilized in one particular instance, over a short period of time, or throughout an entire course and can be done individually or in small groups (Haq, 2017). This particular methodology can be implemented with or without the use of technology. One popular technology tool that has been widely used is clickers. This can be done by creating sets of multiple choice questions for students to respond to during the class lecture using clickers. This is a good opportunity for the professor to gain some feedback about each student's level of understanding and it is also a way for the students to check their knowledge.

IBL can also increase the student's ability to use prior knowledge and newly acquired knowledge to solve problems, build student confidence in his/her ability, and develop the student's teamwork skills.

A modern technique that some professors are using in an effort to improve classroom instruction is called the flipped or inverted classroom. Flipping refers to the process by which a professor disseminates course content prior to and outside of the classroom and then uses class time to implement a variety of active learning techniques (Petrillo, 2016). The flipped classroom can have some positive impact on learning outcomes, student motivation and interest, and overall success in STEM disciplines (Petrillo, 2016).

Perspectives of Active Learning in STEM Education

Since the late 1990s, science educators have been encouraged to implement active learning strategies to model the methods and mindsets that are at the core of scientific inquiry and to offer opportunities for students to connect abstract ideas to real world applications in order to gain skills and knowledge that persist beyond the course in which it was acquired (Allen & Tanner, 2005). Ross and Fulton (1994) conducted one of the earlier active learning studies in STEM education. This study was done over five years in a two course analytical chemistry sequence to assist students in becoming more effective learners in a non-competitive, cooperative learning environment. The researchers describe the process by which the two courses were restructured to incorporate cooperative learning techniques and the distribution of additional study materials to enhance the students' learning experiences in these courses.

The senior comprehensive exam results for all students who took the sequential course were compared for students who were enrolled in the active learning course versus those who were not and the students who were enrolled in the active learning course performed moderately better. When compared to the national norms at that time, the raw scores for 65% of the students who took the standard ACS Analytical Exam Form AN88 were at or above the national average and 20% of the scores were above the 90^{th} percentile; therefore it seems the students under the active learning instruction developed a solid background in analytical chemistry while still gaining the rigor necessary to compete nationally (Ross & Fulton, 1994). The researchers also reported that students thinking and problem-solving skills improved significantly as a result of their participation in this active learning course as demonstrated in the students' ability to listen, formulate questions and answers more carefully, and their ability to defend their answers. Another positive benefit of this implementation of active learning was the improvement in student attitudes toward learning, student development of effective and efficient learning strategies, and an increase in student motivation to excel.

Even with the documented success of some initial STEM active learning studies, sometimes it can be challenging for professors and students to adjust to a 'new' learning technique which is student centered and requires each student to be actively involved in the classroom activities, especially in very large class sizes. Allen and Tanner (2005) focused on active learning strategies that can be used with large class sizes. Specifically, they highlighted the following techniques: (i) beginning and ending the lecture with student discussion questions, (ii) using classroom technology for immediate feedback without requiring the professor to spend time grading, (iii) assigning student presentations and or projects, (iv) using learning cycle instructional models which involve the students at various phases of the learning experience through activities like reading, watching video clips, responding to thought-provoking questions, etc., (v) implementing peer-led team learning, (vi) modeling inquiry approaches, (vii) using problem-based learning and case studies, (viii) developing a workshop course which ties all of the classroom concepts and laboratory experiments together, and (ix) course redesigning or enhancement (Allen & Tanner, 2005). This study highlighted two major active learning strategies, cooperative learning and problem based learning, and also identified many other activities that support student engagement. Although these researchers focused on strategies that work well for large class sizes, all of these techniques can also be implemented effectively in smaller classes as active learning activities.

Along with being strategic about which activities are incorporated into the classroom, when constructing active learning courses it is critical to create a supportive and safe learning environment; set a positive tone in the classroom from day one. Smith, Clarke Douglas, & Cox (2009) presented the how people learn framework and the backward design approach are presented for designing courses that are thoughtfully constructed to optimize student learning. In the how people learn framework there are three components which intersect and are all a part of the learning community, which include learner centered, knowledge centered, and assessment centered instructional strategies. A learner centered atmosphere ties the interests, strengths, and preconceptions of learners to their current academic tasks and learning goals and assists students in identifying how they learn best. Therefore, it is important to check the academic backgrounds and academic majors of students prior to the first day of classes. A classroom setting that is knowledge centered is designed based on an analysis of student learning outcomes and helps students develop the fundamental knowledge, skills, and attitudes needed for successful transfer of this knowledge. An assessment centered environment means providing many opportunities to observe and make evident students' progress from what they currently understand to the ultimate learning goals in an effort to allow students to continue improving their weaknesses and revising their thinking. Providing the students in the class with some type of assessment or knowledge check each week gives the professor and students constant feedback about their progress in the course. Community centered means providing a supportive, enriched, and flexible learning environment inside and outside the classroom where all students can learn, feel comfortable asking questions, and work together (Smith et. al., 2009). All of these elements impact the overall success of STEM course implementation and student achievement academically and professionally. The backward design process requires the professor to do the following: (i) identify learning outcomes, (ii) determine what assessments will be used, and (iii) plan instruction with a focus on student engagement pedagogies (Smith et. al., 2009).

In summary, increasing the sense of community among STEM students and between students and professors within STEM classrooms is valuable, since cooperative learning researchers and practitioners have shown that positive peer relationships are important to overall college success. More supportive and engaging learning environments can help us accomplish our most important outcomes for STEM graduates: stronger critical thinking and reasoning skills, problem formulation and problem-solving skills, skills for working in a team, and confidence in developing solutions to practical problems (Smith et. al., 2009).

In a synthesis of research, Eison (2010) reported that active learning instructional strategies can be developed and implemented to engage students in creative or critical thinking, which can be done in pairs, groups, or as a whole class. This study highlighted some successful studies that have been done with large numbers of students in different types of STEM courses and the importance of students' engagement in their learning. It was also noted that active learning does not require technology and it can be done can during class time or outside of class time. In this study a combination of instructional strategies are highlighted and the differences between traditional lecture and interactive lecture are described.

According to Eison (2010), there are some challenges when implementing an active learning instructional methodology. For example: the professor may not be able to cover as much course content within the class time available, preparation for active learning activities may require more time, large class sizes may impede implementation of active learning strategies, a lack of materials or equipment needed to support active learning approaches, and students may resist non-lecture approaches (Eison, 2010). As a result, it is useful for the professor to begin with traditional instructional strategies and build up to including more student centered activities.

The lack of academic engagement in introductory STEM courses is considered to be a leading reason students change to non-STEM majors (Gasiewski et al., 2012). Recognizing the connection between student engagement and student performance, the physics faculty at a southern university adapted a model of active, collaborative, inquiry-based learning for their introductory calculus-based physics courses (Gatch, 2010). In the fall semester of 2006, the faculty piloted its first studio course; a course that seamlessly integrated the lecture and laboratory courses into one course with much of the class time devoted to student-centered learning. The number of studio courses increased each semester until the full implementation of studio courses in fall 2008. Assessments of student learning outcomes and surveys of student attitudes were conducted throughout the conversion from lecture and laboratory courses to the studio courses. The Force Concepts Inventory (FCI) and the Maryland Physics Expectations Survey (MPEX) were used for students enrolled in Physics I; and the Conceptual Survey in Electricity and Magnetism (CSEM) and the Colorado Learning Attitudes about Science Survey (CLASS) were used for students enrolled in Physics II. Results indicated that students completing the Physics I and Physics II studio courses had greater learning gains than students who took the traditional courses. The results from the MPEX showed positive shifts in the independence, math link, concepts, and reality link categories; negative shifts were seen in the coherence and effort categories. Similarly, the CLASS showed positive shifts in all categories that were measured for the Physics II students (Gatch, 2010).

The decision of the faculty to adapt the studio model with student-centered active learning strategies was supported by the results of the research. Although there was no disaggregation of the data to reveal any underlying trends in areas such as previous academic history or ethnicity, the restructuring of the introductory physics courses has created a format that allows for increased student engagement which is linked to student performance.

Another study, by Freeman et al. (2014) produced an extensive quantitative analysis of active learning research in college STEM courses. The researchers tracked and analyzed studies from and found that 642 of them met the criteria of: (i) contrasting traditional lecturing with any form of active learning, (ii) occurring in the context of regularly scheduled undergraduate courses, (iii) being limited to changes in how the classes were conducted, (iv) involving a course in astronomy, biology, chemistry, computer science, engineering, geology, mathematics, environmental science, food science, physics, psychology, or statistics, and (v) including data on student performance. Further analysis of these studies narrowed the research to 225 studies that had examination equivalence, student equivalence, instructor equivalence, and data that could be used for computing effect size (Freeman et al., 2014). A meta-analysis of those 225 studies gave a result consistent to the results of less rigorous studies – active learning strategies achieve measurably better student performance outcomes. The research showed that students in classes taught by traditional lecture were 1.5 times more likely to fail than students taught in active learning classrooms. When analyzing the data collected and examining the type of course and the level of course offered, there was statistically no significant difference in how active learning impacted students in any of the courses (Freeman et al., 2104).

The active learning approach produced the same positive effect in all of the courses throughout all STEM disciplines. Active learning is a broad term that incorporates many techniques. Although the study has important implications for college level STEM education, it does not confer a type of active learning as being more beneficial to student performance than another. An implication of the study for further research in college level STEM education is the comparison of the impacts of different active learning strategies on student performance. Further research could be expanded to include findings of the impact of active learning on underrepresented minorities who do not complete undergraduate STEM degrees at the same rate as their counterparts.

As student centered learning strategies become a mainstay in STEM education reform, problem based learning helps to prepare students to deal with the complex problems they will encounter in the real world. This learning strategy is well suited for engineering education because functioning as an effective member of a team to solve complex problems that are not well structured is what engineers do in practice. In an investigation of PBL in an undergraduate electrical engineering course in a large mid-western university, Yadav, Subedi, Lundeberg, & Bunting (2011) used traditional lecture as the baseline phase and PBL as the experimental phase to compare the learning gains of students from PBL and traditional lecture. Instructor-developed pre-tests and post-tests assessed knowledge and conceptual understanding. The study showed that learning gains from PBL were almost twice as high as learning gains from traditional lecture (Yadav et al., 2011). This technique worked best in advanced courses with students who have already acquired strong fundamental skills. This study adds to the body of empirical data to support PBL as an effective instructional strategy, but more research needs to be done in this area.

Another study was conducted at a large research university in an introductory biology course with a high number of students in order to make time for in class cooperative learning activities which focused on critical thinking (Prunuske et al, 2012). There were 130 students selected through a competitive application process for enrollment in this course and they were informed before the first day of class about way the course would be conducted. The researchers in this study assigned a series of short online lecture notes for students to read prior to the class meeting where the topic would be covered so that in class time could be used to focus on doing examples and checking student knowledge. In addition, clickers were used during class time to assess student knowledge.

This study showed based on student survey and performance on basic level questions advantages in utilizing these active learning techniques. There are some benefits to curricular redesign that integrates in-class cooperative learning activities and technology, like online lectures and the use of clickers in class (Prunuske et al, 2012). This particular institution has a small percentage of minority students, which is a limitation of this study.

In an inquiry-based learning study, Kogan and Laursen (2014) reported modest change when comparing grades in subsequent classes of students who took IBL college mathematics courses to the grades of students who took non-IBL courses. In a large scaled mixed methods study involving four universities with IBL Math Centers, the researchers used students' academic records, observations, interviews, surveys, and test data to assess the long-term effects of IBL in college mathematics courses. From the observation study, the researchers found that the students in the IBL courses asked more questions and took on more leadership roles in the classroom. In the IBL courses, 60% of class time was spent on student-centered activities; whereas in the non-IBL courses, over 85% of class time was spent on professor lecture. Courses were chosen because they had an adequate amount of students enrolled in both IBL sections and non-IBL sections, their placement was early in the course sequence, and they were taken early enough to have subsequent courses taken at the time of the study (Kogan & Laursen, 2014).

When disaggregating the results by prior achievement, this study showed that the performance of low-achieving students improved after taking IBL courses when compared to their own prior achievement and to the achievement of students who did not take IBL courses. When disaggregating for gender, the study revealed that the impact of having taken IBL courses was mainly effective for women. Women taking non-IBL courses had a similar success to men, but reported lower confidence at the end of the course. The study further showed that even though less material was covered in IBL courses due to the time given to student-centered activities there was no adverse impact on the students' performance in subsequent classes. It provided evidence that IBL strategies can have lasting effects on groups of students whose prior mathematics achievement may have been low. Thus, this study supports the premise that active learning can improve student outcomes.

As the popularity of the flipped classroom learning strategy has increased, studies have been done to determine the impact of this technique on student achievement. Sahin, Cavlazoglu, and Zeytuncu (2014) sought to answer these questions in a study of 96 students in a college calculus class in the spring 2013 semester at a college in Texas. In this class, three subjects were taught using the flipped classroom method and seven subjects were taught using traditional lecture method.

They found that quiz scores of the students were significantly higher for the subjects taught using the flipped classroom method than for the traditionally taught subjects (Sahin et al., 2014). Through survey, they also found that the majority of the students felt that the flipped classroom strategy helped them to perform better. The results of this study align with the results of similar studies on the flipped classroom learning strategy.

In a subsequent study on the flipped classroom, Petrillo (2016) examined the effectiveness of the flipped classroom on student grades in the class and student attitudes/perceptions about their experiences in a flipped or inverted style class. This study was conducted at a small, comprehensive, American university that has a school of engineering to determine if the flipped classroom concept would improve student success rates in first semester college calculus in response to the high failure rate of students in the course.

A comparison of the success rates for the lecture (fall 2005-spring 2009), lecture with activities (fall 2009-spring 2012), and flipped classroom (fall 2012-fall 2014) models was done. The flipped classroom model showed the highest success rate at 69.5%; followed by lecture with activities at 64%; and lecture at 57.4%. In addition, student surveys were used to gain insight into students' opinions about the course content and the instructional strategies. Due to their success with the flipped classroom implementation, Petrillo (2016) indicated that this method has been adopted as a standard American Chemical Society (ACS) for Calculus I and a comparable course for Calculus II is in the developmental stage.

Cronhjort, Filipsson, and Weurlander (2017) conducted a study in which certain sections of a class were taught using the traditional lecture method and other sections of the course were taught using a flipped classroom technique yet all student participants were administered the same Calculus Baseline Test which included 15 multiple choice questions divided into three categories: pre-calculus, calculus concepts, and calculus theory and formalism. This test was given as a pre-test in the beginning of the semester and as a post-test at the end of the course prior to the final exam. In addition, student participants were given final examinations and student engagement surveys.

The findings of this study indicated that the flipped classroom benefited students learning and overall experience in the classroom. The failure rate decreased more and the highest grade increased more in the flipped classroom compared to the lecture class. This indicates that the flipped classroom benefited low and high-performing students (Cronhjort et al., 2017). Similarly, Petrillo (2016) found that the failure rate decreased when the flipped classroom technique was implemented in the calculus course.

Based on the survey results in Cronhjort et al. (2017), students enrolled in the flipped classrooms felt more engaged and believed that they were a part of a learning community in which they were fully involved and contributed to the learning experience, instead of feeling like isolated independent learners. One setback of the flipped classroom is that students with special needs can find certain aspects of the classroom setting challenging (Cronhjort et al., 2017).

This study can be augmented by implementing different types of active learning strategies and creating experiences that facilitate thinking, questioning, application, and peer interactions. In an effort to determine if the flipped classroom approach had a greater impact on student performance than traditional and online approaches in a C# programming course, Sharp and Sharp (2017) conducted a quantitative research study. The study comprised eight semesters from fall 2012 to spring 2016 and 271 participants enrolled in an introductory C# programming course.

The data collected each semester were lab assignment scores, exam scores, final exam scores, and overall course averages. The data analyses revealed that student learning increased with the flipped instructional approach when compared to the traditional approach and that additional research must be done to compare student academic performance between online approaches and the flipped classroom approach (Sharp & Sharp, 2017).

The study was limited by the number of participants in each method. Of the 271 participants, 136 were in traditional sections, 96 were in online sections, and 39 were in flipped sections. The results of this study could be strengthened with more students in the flipped sections. This study does, however, extend the body of work that supports student-centered learning approaches such as the flipped classroom model.

What follows is Table 1, which summarizes the active learning perspectives in college level STEM education that were presented in this paper. The type of institution, type of course, techniques implemented, and the findings are outlined in Table 1. For the sample size, N represents the total number of students participating in the study and n represents the number of students participating in the active learning components. Overall, the results of the research showed that active learning techniques enhanced student performance and increased learning gains.

Discussion

This paper reviewed analyses of active learning approaches in college level STEM courses. Throughout our review, we have shown that there is a relationship between student engagement and student learning. Based on the studies reviewed, student engagement in the learning process enhances student academic performance, increases student interest and motivation, and better equips students with the ability to apply the knowledge and skills gained in their STEM courses to real-life problems.

Table 1. Active Learning Studies in Undergraduate STEM Education

Researchers	Sample	Course	Technique	Findings
Ross and Fulton (1994)	students at a private liberal arts college *(N=65, n=39)*	analytical chemistry two course sequence	cooperative learning	Students in active learning courses performed better than students who were not.
Gatch (2010)	students at a large research university	Physics I, Physics II	inquiry-based learning studio courses	Learning gains were greater in studio courses than in traditional lecture and lab courses.
Yadav, Subedi, Lundeberg, and Bunting (2011)	students at a large mid-western university *(N=55, n=55)*	electrical engineering course	problem-based learning	Learning gains from PBL were almost twice as high as learning gains from traditional lecture.
Prunuske, Batzli, Howell, and Miller (2012)	students at a large research university *(N=130, n=130)*	introductory biology course	cooperative learning and online lecture	Students performed better on lower-order cognitive skills questions.
Kogan and Laursen (2014)	students at two universities hosting IBL Math Centers *(N=2447, n=383)*	various mathematics courses	inquiry-based learning	Low achieving students improved after taking IBL courses.
Sahin, Cavlazoglu, and Zeytuncu (2014)	students at a college a university in the south *(N=96, n=96)*	Calculus	flipped classroom	Scores were significantly higher for students taught using the flipped classroom method.
Petrillo (2016)	students at a small comprehensive university *(N=530, n=473)*	Calculus	flipped classroom	The flipped classroom model showed the highest success rate.
Cronhjort, Filipsson, and Weurlander (2017)		Calculus	flipped classroom	The failure rate decreased and the highest grade increased.
Sharp and Sharp (2017)	*(N=271, n=39)*	introductory C# programming course	flipped classroom	Student learning increased with the flipped classroom approach.

However, there can also be some challenges associated with adjusting the method of instruction to include active learning. These challenges are related to the professor modifying the way they teach and student reception of and preparedness for a classroom setting with less traditional teaching strategies. Some of these challenges include the following: (i) inability to cover all of the required material, (ii) the amount of time a professor may need to spend on preparing the modified instruction, (iii) ensuring that the adjustments match well with the professor's personality and the student population in the respective class, and (iv) lack of equipment or resources to make the desired change. Therefore, it is critical for the professors to determine based on their institution and the institution's student population what modifications can be made and include them gradually, if necessary, to avoid some of the potential challenges.

There are a variety of ways to incorporate active learning strategies into college level STEM courses. Some strategies are designed to encourage each student to express his/her attitudes and values towards the subject matter and others are designed to increase retention of the material presented in the class. With the goal of increasing student academic performance, what follows are three examples of activities that can be used to enhance student engagement (California State University). A reading quiz can be used to check student comprehension of the assigned readings to help the students identify how to perceive the most important parts of what they read. Student summary of another student's answer can be used to promote active listening. After a student answers a question, another student can be asked to summarize the first student's response. Concept mapping can be used to help students identify the connections that exist between terms or concepts covered in the course material. This method usually assists students with thinking deeper about the concepts and understanding the material at a higher level.

Technology is another valuable tool that can be used to complement active learning teaching strategies. Depending on the type of technology utilized, it can be used during class time or outside of class time.

Many professors are using online learning components, which have been shown to improve student academic performance (Prunuske, 2012). Online videos, clickers, or online platforms for discussions/posts/homework are all examples of ways technology can be incorporated into college level STEM courses.

Learning is active, personal, and intentional, not a passive process (Ross & Fulton, 1994). Studies indicate that active learning has been effective in engaging students in the learning process. Moreover, students actively engaged in their own learning experience increased learning gains and enhanced retention of course material; therefore, they are more likely to persist in STEM majors.

Suggestions for Future Research and Practice

The United States has developed as a global leader, in part due to the intelligence and efforts of scientists, technologists, engineers, and mathematicians. To ensure our nation's continued scientific and technological growth and advancement, supporting undergraduate student success in science, technology, engineering, and mathematics disciplines is paramount (Espinosa, 2011). Currently, there are not enough people from diverse populations, including women, participating in the STEM academic and professional communities. Therefore, to remain as a competitive nation in STEM, it is critical to create learning opportunities and pathways for all students, including those from groups traditionally underrepresented in STEM, who are interested and capable of pursuing education and careers in these fields. The need to broaden participation in STEM is especially important for those who identify as African American or Black (Upton and Tanenbaum, 2014). In that regard, Historically Black Colleges and Universities may have a unique advantage in the nation's efforts to significantly increase the participation of this population (Upton, 2014). To support this effort, improved STEM pedagogical practices, like active learning techniques, have been on the horizon for years. Recently, these methods have gained increased significance given the desire of educators to increase the numbers of women and minority students in STEM with the overall goal of using innovative teaching strategies to benefit all students (Espinosa, 2011).

The value of the diversity of students is recognized when active learning is implemented in STEM courses (Prunuske et al., 2012). As the body of worked on active learning strategies in undergraduate STEM education expands, future research should focus on the impact of innovative teaching strategies on underrepresented groups. It is important for professors at all types of institutions to search for new ways to engage all students and enhance the learning environment since the dynamic between faculty and students in STEM courses impacts the students overall learning experience. If professors engage students from diverse backgrounds, they are more likely to excel and persist in STEM majors.

There are several open questions related to the impact of active learning teaching techniques in college level STEM education. Future research in undergraduate STEM education should include the following: how to optimize the use of technology in STEM courses, how to integrate course content across STEM disciplines, how active learning in a prerequisite course effects performance in subsequent courses, and how active learning impacts student graduation rates in STEM majors. Increasing the girth of knowledge on best practices in college level STEM education will lead to the United States maintaining its position as a leader in science, technology, engineering, and mathematics.

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