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A Meta-Analysis Examining the Efficacy of Flipped Instruction for STEM Academics

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This is to certify that the doctoral dissertation by

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Abstract

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MS, Walden University, 2010

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Abstract

Improving education, particularly for the sciences, is an important and necessary endeavor which can lead to positive social change. Education reform tends to involve updating and aligning curriculum standards without considering methodologies or teaching strategies involved. Identifying evidence-based practices to improve achievement in science, technology, engineering, and mathematics (STEM) will contribute to improving the education system. Flipped classroom instruction is a pedagogical approach that emphasizes student involvement and engagement in the learning process. There is evidence that active learning strategies improve achievement in STEM academic areas. The purpose of this study was to compare traditional lecture teaching methods to the flipped classroom approach in terms of measures of academic achievement using a meta-analysis. Data for this study measured achievement of flipped and traditional pedagogies in STEM areas. Results from this meta-analysis were not significantly in favor of a flipped approach. However, only one study favored traditional lectures over flipped approaches, while other studies showed a small to moderate effect size in favor of the flipped approach. Implications for positive social change include discussion of effective teaching strategies that promote academic achievement and retention in STEM areas.

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Dedication

This work is dedicated to my children, my family, and my students. This journey has been long and difficult but the constant support I have received from my people has been invaluable. For allowing me the time to work, a safe place to discuss ideas and frustrations, and the inspiration to keep going especially when giving up would have been easier; I am forever grateful.

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Chapter 1: Introduction to the Study

Introduction

United States high school students continue to be below average on science proficiency scores compared with other industrialized nations. In 2012, approximately 70% of American students failed to demonstrate college-readiness in science academic areas (Biba, 2013). According to the Pew Research Center (2015), less than half of advanced degrees earned for science, technology, engineering, and mathematics (STEM) were earned by American students. Foreign college students accounted for 57% of advanced doctoral engineering degrees and 53% of computer and information science doctoral degrees. Although education reforms are underway that aim to increase science literacy and achievement, there are no clear implementation strategies in place to guide educators. Therefore, educators are left to decide on their own which pedagogical approaches are the most effective and conducive for learning. Approaches include traditional lectures with accompanying textbook homework, online learning resources, assessments, and more recently, the flipped classroom paradigm. According to the Flipped Learning Network (2014), a flipped classroom is a pedagogical approach in which direct instruction moves from group to individual learning spaces, and the resulting group space is transformed into a dynamic and interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter.

Inquiry-based teaching methods have been shown to be conducive in terms of learning how science works because they rely on a student-centered approach that promotes active learning (Barrow, 2006). However, science and advanced mathematics courses are content heavy, and instructors are tasked with ensuring that students understand the subject matter thoroughly. Naturally, the traditional lecture approach is often used as this approach allows for the dissemination of information that students need to be able to use. The result is that the classroom becomes a teacher-centered learning environment, even though literature most often supports student-centered inquiry. Flipping the classroom is a feasible solution because content and information dissemination can take place outside of the classroom, which frees up class time for student-centered learning. For these reasons, flipped classrooms have become increasingly popular as a means of engaging students and allowing them the opportunity to actively participate in the classroom through activities and laboratory investigations (Anderson & Brennan, 2015; Enfield, 2013).

Problem Statement

Flipped classrooms have been shown to be effective at engaging students and increasing academic achievement, particularly in STEM courses (Munson & Pierce, 2015; Talley & Scherer, 2013). However, there is considerable diversity in terms of implementation, style, student ability, teaching experience, learning environment, and population demographics (Makice, 2012; Moravec et al., 2010; Papadopoulous & Roman, 2010; Pierce & Fox, 2012). There is a need to investigate various methods that are employed in these classrooms to ascertain which are most effective in terms of promoting learning and increasing student motivation. Overmyer (2015) said there is little benefit to switching components of a traditional-homework pedagogy without introducing inquiry-driven approaches as well.

Creating a 21st century science classroom model that is effective in terms of engaging students and provides effective learning experiences is a complex task and can be a financial burden for many school districts (Flumerfelt & Green, 2013). If flipping the classroom leads to a shift toward more active participation and increased achievement for STEM academic areas, educators should consider this shift even if a large initial investment is required. The old paradigm of viewing science education as a series of facts and body of knowledge that students must remember may need to be replaced (Doulik & Skoda, 2009). Studies that have examined the efficacy of flipped classroom pedagogies as compared to traditional approaches have reported varying degrees of success. However, this may be due to variations in terms of implementation of the flipped approach, teacher experience (or inexperience) involving using the flipped approach, student ability, quality of flipped video lessons, and level of inquiry that students engage in while in the classroom (Anderson & Brennan, 2015; Overmyer, 2015).

It is unclear how these variables factor into the overall success or failure of the flipped approach to improve achievement in STEM academic areas. Furthermore, there is little agreement across studies in terms of how much more effective the flipped approach is compared to traditional lectures. Considering financial and time commitments that are necessary to train teachers about the flipped pedagogy and create content-specific video lessons, it is imperative for educators to know how effective the approach actually is so that they may make educated decisions before switching paradigms.

Although the efficacy of inquiry-based methods and problem-based learning (PBL) have been examined previously, there exists a lack of conclusive evidence regarding how these methods have been incorporated successfully into a flipped learning paradigm using currently available technology. This research was focused specifically on use of flipped classroom methods that incorporate some degree of inquiry-based methods during classroom time. The proposed quantitative study which involved using a meta-analysis was used to determine the effectiveness of flipped classroom approach in terms of increasing academic achievement in STEM academic areas. The proposed research will serve an additional purpose of identifying potential moderators of effects of flipped learning.

Purpose

The purpose of this meta-analysis is to obtain a true estimate of effect size for achievement outcomes in classrooms that employ a flipped or inverted instructional pedagogy. Additionally, possible moderating variables were determined as well as their effects on achievement outcomes. Specific moderating variables were identified once preliminary effects sizes were computed for various studies that were included in this meta-analysis. According to Abeysekera and Dawson (2015), it is important for a uniform and operational definition of the flipped classroom. The operational definition of flipped learning is a key component in terms of evaluating the body of research that exists regarding efficacy of flipped learning in terms of improving student learning outcomes. Furthermore, these researchers caution the use of flipped learning as a wide-spread pedagogical approach before further investigations take place. In particular, these researchers call for a meta-analysis approach to provide both a working operational definition of flipped learning and show the true effect size that this approach may have on improving student learning and engagement (Abeysekera & Dawson, 2015).

Significance

Curriculum reform and best science education practices continue to be major areas of study for educational psychologists and researchers. Inquiry teaching is a strategy that is effective in terms of instilling critical thinking and problem-solving skills that are necessary for academic success in science. Flipped classrooms allow teachers to spend the majority of class time engaging students in meaningful and inquiry-based activities. There is diversity in terms of how educators implement this approach (Barrow, 2006; Brooks, 2006). Furthermore, the literature shows some discrepancy in effect sizes that flipped classroom instruction has in terms of measures of achievement.

Improving education, especially for the sciences, is an important endeavor that will impact society. Increasing science literacy and motivating more young people to pursue careers in science will lead to positive social change. Educators need to be aware of best educational practices to guide students toward understanding how science works so they can develop critical thinking skills and scientific literacy.

Background

The most common type of flipped instruction involves the format of active learning in the classroom and passive learning at home. This means students engage in out of class work that may include reading, watching lecture videos, and presentations such as PowerPoint or Prezi. Students engage in active learning tasks while in the classroom that include project-based learning, inquiry-based learning, collaborative learning, problem-solving tasks, and traditional homework assignments. According to Herreid and Schiller (2013), success in these types of flipped learning environments is dependent on both the quality of instructional materials that students are accessing outside of the classroom and student preparation. It is also important for instructors to tailor lessons and activities to promote active learning while in the classroom.

The body of literature on using the flipped approach is large and diverse. These studies differ in terms of specific outcomes, implementation strategies, teacher preparation and experience, sample size, and subject matter of the course that is using the flipped approach. Furthermore, some studies describe a flipped classroom that is more of a hybrid pedagogy that involves some flipped components but is still mostly a lecture-based paradigm.

Studies that focus on achievement as an outcome have yielded mixed results regarding efficacy. The construct of achievement has been operationally defined and measured using standardized tests and assessments in many studies that examine the effect of flipped instruction. Harrington et al. (2015) examined achievement in flipped classrooms among students in an undergraduate nursing program and noted small to moderate effect sizes that are further limited by a small sample size. There was no significant difference in terms of achievement, which may also be due to the small sample size. Geist et al. (2015) said flipped classrooms were significantly more effective compared to lecture-based methods. Munson and Pierce (2015) examined the effect of flipped instruction on student grade point average. Davies et al. (2013) used a pretestposttest design to examine effects of technology-infused flipped approaches on student achievement. Improved academic performance and student motivation have been linked to flipped instructional methods (Davies et al., 2013; Enfield, 2013; Talley & Scherer, 2013).

Motivation and student engagement are also outcomes that researchers have focused on when comparing flipped learning to traditional lecture approaches. Mavromihales and Holmes (2016) examined student engagement levels in an engineering course via survey and questionnaire data from 100 participants and found students favored the flipped approach and reported higher levels of engagement with the material, instructors, and peers. Mylott et al. (2016) focused on outcomes of student engagement in a flipped learning environment with health science students taking an introductory physics course and said a significant number of students displayed positive responses to the flipped approach, and these students reported the approach helped them make real-world connections between physics and the biomedical field.. McLaughlin et al. (2013) said significantly more students in an introductory pharmaceutics course preferred the flipped format upon completion of the course. Student empowerment, development, engagement, and academic performance were enhanced. White et al. (2017) said student preparation was a critical factor influencing student success with the flipped approach. This indicates that teacher preparation of materials that are engaging and ensure students complete passive learning components is an important variable in the flipped approach.

The available body of research on the flipped approach is diverse, but there are key similarities between studies that show advantages of this pedagogy. Whether studies focus on academic achievement or student motivation, the flipped approach appears to be most effective when students are encouraged to engage with material and are allowed to collaborate effectively with peers. Although methodologies and specific outcomes of each study vary, there is a common theme among them: student engagement improves student achievement. Via the flipped classroom approach, students are more actively engaged with course content, and this may lead to improved academic outcomes compared to the traditional lecture approach.

Framework

This research is guided by the assumption that inquiry-based learning is effective and flipped classroom instruction is a viable way for educators to apply these concepts in the classroom. Student-centered learning is the theoretical framework that guides implementation of a flipped classroom. The main tenets of student-centered learning that originate from the work of Piaget and Vygotsky are the promotion of active learning through collaboration and constructivism (Fox & Riconscente, 2008). The constructivist theory emphasizes the role of peer cooperation, guided inquiry, and problem-solving to maximize student motivation and achievement. Flipped classrooms are centered on the idea that classroom time is active learning time while all passive learning (such as lectures and reading) take place outside of the classroom. The flipped classroom is student-centered, and the teacher becomes a facilitator whereby the main role of the instructor is not to disseminate knowledge but provide meaningful learning experiences that include collaborative and inquiry-based activities. Removing traditional lectures from science and mathematics courses improve student performance, as lectures are not particularly effective at improving student skill levels or problem-solving abilities (Abeysekera & Dawson, 2015).

Nature of the Study

A meta-analysis approach was used to address research questions through a review of previous research on flipped classroom efficacy. This approach was appropriate to understand the true nature of the effect of using flipped instruction on science achievement across diverse populations and academic environments. Additionally, it provided insight concerning the impact of flipped classrooms in terms of increasing achievement over traditional lecture approach.

Research Questions

RQ1: To what extent do standardized achievement test scores of flipped and traditional classrooms differ?

Additionally, the following subquestions were addressed:

SQ1: What is the range of effect sizes, including 95% confidence intervals, for flipped-class instruction in STEM courses?

SQ2: What is the overall mean effect size for academic achievement in flipped classroom strategies, including 95% confidence intervals, when compared to traditional lecture strategies?

SQ3: Do effects sizes from individual studies differ from the overall mean effect size based on particular moderator variables, such as academic subject, student population, experience of teacher, and other demographic variables?

Types and Sources of Data

For this meta-analysis, both published and unpublished research articles were examined. Studies involving the effect of flipped instruction on improving academic achievement were included in analysis. Studies were similar in terms of outcomes and measures in order to achieve reliability and validity of this meta-analysis. Outcomes of achievement were operationally defined and involved excluding assessments that were not standardized measures of achievement. Studies that focus on instruction outside of the STEM domains were excluded. Viable research studies were located through a comprehensive search of all available databases in the Walden University Library. Additional searches for viable research studies involved using outside databases such as Google Scholar and PLOS One. Google Scholar ensured unpublished research articles were considered if they existed. Flipped classroom instruction involves passive components of learning taking place via technology-based instruction such as online video lectures, podcasts, and presentations. For this reason, studies published prior to 2002 were excluded from this meta-analysis. Certain technological advancements that have made online instruction and flipped approaches a viable option did not exist prior to this time.

Definition of Terms

Effect Size: The size of impact of a particular treatment on an outcome measure. The effect size can be used to describe the relationship between two variables (Borenstein et al., 2009). For the purposes of this study, effect size for the outcome variable of academic achievement was compared for two different treatment groups: flipped classrooms and traditional lectures.

Flipped Classroom: Instructional pedagogy that flips active and passive learning components of a traditional classroom (Davies et al., 2013). In a flipped classroom, homework, practice, and activities are an integral part of the school day. Passive learning components such as reading and watching a lecture are reserved for outside of school time.

Lecture: Instructional method that is not interactive or highly engaging. A lecture involves the direct dissemination of information from the instructor to students (Dennen, 2004).

Meta-Analysis: A method of systematically adding effects of many quantitative studies to arrive at a single conclusion that provides greater statistical power compared to any one single study (Ghahramanlou-Holloway, 2007).

Problem-Based Learning (PBL): Active learning strategies that serve a variety of instructional purposes. Generally, PBL involves the following three major components: narratives, response/activities, and debriefing (Brooks, 2006).

Assumptions

I assumed studies included in this meta-analysis accurately measured academic achievement as outcome variables. Furthermore, validity, reliability and precision of literature was accurately portrayed. These assumptions are necessary in order to calculate weighted effect sizes while conducting analysis. I also assumed all available studies that met inclusion criteria were located and included in the final meta-analysis.

Scope and Delimitations

The proposed study involves a focus on research studies that compare the flipped classroom pedagogy to traditional lecture approaches, specifically in STEM areas. All included studies were similar in that outcome variables were academic achievement and studies were quantitative in nature.

Limitations

Due to the focus on academic areas that were specific to STEM education, conclusions about achievement in other academic areas were not made. This study was limited to a discussion of only the effects of flipped pedagogy on STEM disciplines. Furthermore, results of the study will not be applicable to younger groups of learners who may also benefit from the flipped approach.

Summary

The flipped classroom approach is based on the idea that active learning should take place in the classroom, while passive learning should take place outside of the classroom. Although not a new pedagogy, the flipped approach has gained momentum over the last decade as teachers attempt to provide more engaging and enriching learning environments. The flipped approach can be incorporated across a variety of academic disciplines. However, the approach seems especially conducive for teaching 21st century skills necessary for academic achievement in STEM areas. Ideals that are inherently reinforced through a flipped classroom include constructivism, social learning theory, and inquiry approaches to the learning process (Gonzalez-Gomez et al., 2016).

This meta-analysis involved establishing a clearer understanding of the efficacy of flipped classroom instruction on improving academic achievement in the STEM disciplines via comparisons with the traditional lecture approach. Studies that were included in this meta-analysis involved these academic areas only. Chapter 2 includes theoretical aspects of the flipped pedagogy, inquiry learning, and PBL, as these approaches specifically apply to STEM instruction. A comparison between flipped and traditional approaches was included along with a discussion of components of education that are conducive to active learning.

Chapter 2: Literature Review

Introduction

This literature review includes a discussion several learning theories, including the inquiry-based learning theory, constructivism, and engagement. Each of these theoretical frameworks provides a foundation for the flipped classroom pedagogy, which guides this meta-analysis and its relationship with achievement outcomes for STEM students. This literature review also includes benefits associated with flipped classrooms as they relate to STEM education and increasing student engagement in these academic areas. Furthermore, variations in terms of implementation of the flipped approach are also discussed.

Literature Search Strategy

Education-related databases were primarily used to conduct this literature review due to the nature of the study. Interdisciplinary databases were also searched and largely yielded information that was pertinent to research questions. Although the main purpose of the literature review was to obtain relevant literature, it also served to identify potential candidate studies for this meta-analysis. Both peer-reviewed and nonpeer-reviewed research was included. Additionally, I searched for published research articles and conference papers without limits on date or population. The following databases were used: Education Source, Education Research Complete, ERIC, Science Direct, SAGE Premier, Academic Search Complete, PsycINFO, and ProQuest Central. Search terms used were: *flipped classrooms*, *inverted classrooms*, *flipped pedagogy, lecture, science,* *STEM*, *flipped instruction*, *constructivism*, *inquiry methods*, *collaborative learning*, and *cognitivism*.

Definition of Flipped Classrooms

A flipped or inverted classroom is any classroom that reserves class time for active learning activities that include practice, peer collaboration, and problem-solving. Additionally, this paradigm allows and expects students to engage in passive learning outside of class time, which includes use of technology to facilitate transmission of knowledge and course-specific content that would normally be part of a lecture (Love et al., 2014). Flipped classroom instruction is an inductive strategy in which students are presented with learning opportunities through relevant examples. Using these examples, students construct their own meaning and understanding of each learning concept (Clark, 2015).

Implementation of the flipped classroom can vary from one classroom to another, but the core concept is that active learning takes place in the classroom while passive learning takes place at home. Essentially, homework and lecture components of the traditional classroom are switched (Clark, 2015; Love et al., 2014; McCallum et al., 2015). Allowing students to access lecture materials outside of class facilitates learning because students can self-pace and revisit concepts that may be difficult to grasp. Students also receive additional support and guidance while practicing and applying new concepts through interactions with classmates and course instructors. In STEM areas, the flipped model of instruction is particularly appealing. While some teachers worry that the flipped approach interfere with content coverage, teachers who have applied the technique successfully boast of higher engagement and student achievement.

The advantages of the flipped classroom are not limited to engagement. When students are allowed to access lecture materials outside of class, they gain control over the pace of learning. Additionally, they are able to work toward an understanding of difficult concepts in collaborative and supportive environments. Educators benefit from this arrangement as well because they are better able to make formative assessments which provide valuable insights into student difficulties. The course curriculum can then be easily adapted and updated to enhance learning experiences for individual students based on their learning styles.

Overmyer (2015) said the flipped classroom is not simply homework at school and lectures at home, but instead involves incorporating active learning strategies during classroom time that increase student engagement and encourage peer collaboration and problem-solving. Student engagement is correlated with achievement (McLaughlan et al., 2013; White et al., 2017). The flipped approach maximizes student engagement, resulting in higher achievement scores and academic success.

Literature Gap

The association between flipped classroom instruction and achievement in STEM courses is still unclear, as there appears to be conflicting research on the effect of outcome measures (Love et al., 2014). This may be due to additional variables that can impact overall achievement and learning in the classroom. Many evaluations of flipped learning have focused on convenience benefits to students using this approach (Foster et al., 2016). These studies have generally applied survey methods to assess student perceptions of a flipped or inverted classroom and these studies have reported mixed results regarding student performance. The main benefit to students are that the material can be accessed multiple times through the use of technology allowing students to acquire information anywhere, not just in the classroom (Foster et al., 2016).

Freeman et al. (2014) assessed the efficacy of active learning over passive learning through a meta-analysis of 225 research studies that each focused on academics in STEM areas. Active learning classrooms varied in terms of intensity and implementation. Classroom were labeled as active learning environments if they included at least occasional collaborative problem-solving or worksheets. Active learning increases student achievement and decreases failure rates compared to traditional passive learning strategies. Specifically, the active learning environment increased student achievement by almost one half a standard deviation. Furthermore, traditional lecture approaches in STEM classrooms increased failure rates by nearly 55% (Freeman et al., 2014). Although active learning is beneficial in STEM classrooms in terms of increasing conceptual understanding, it is still unclear how learning environments that are completely active impact achievement. About 15% of class time was devoted to active learning tasks. A flipped classroom approach, which involves employing active learning strategies for the majority of class time, may be even more effective in terms of increasing student achievement.

Overmyer (2015) said quality of flipped instruction matters when it comes to student achievement. Students who took a flipped college Algebra course in a classroom with an instructor who had experience with inquiry-based and cooperative learning methods scored significantly higher on the common final exam compared with traditional lecture sections. Flipping passive and active strategies may not be enough to increase achievement in STEM academic areas. Approaches that teachers employ during face-to-face classroom time are important components in terms of student achievement. Inquiry, whether guided or not, and peer collaboration involving problem-solving may be key components in terms of success of flipped classrooms. Flipping the classroom has no positive or negative effect on student achievement compared to traditional lecture approaches (Clark, 2015; Overmyer, 2015).

Research indicates there is a need for more comprehensive understanding of the possible link between flipped instruction and student achievement. Although studies have indicated that flipped or inverted classrooms have equal or higher rates of student achievement and conceptual understanding; it is still unclear how much of a difference flipping the classroom makes or if the inquiry aspects are more indicative of student success. It is also unclear if there is a significant academic advantage of the flipped approach over the traditional lecture approach due to the mixed results reported by the literature and the variations in implementation strategy (Foster et al., 2016; Mattis, 2015).

Constructivism

The model for the flipped learning paradigm is based on constructivism. The assumptions of the constructivist model is that learning is an active, social process. That is, students actively construct an understanding of concepts and material through experiences that allow the learner to build upon previous knowledge.

The main idea of constructivism is that learning cannot take place through passive interaction with new information. According to Piaget's theory of cognitive constructivism, learning occurs when students actively engage in meaningful interactions with both the material and other people within the learning environment (Kugelmass, 2007). Spontaneous learning, such that occurs in early childhood, is most conducive to learning science because of the high level of inquiry involved. Inquiry based science education (IBSE) approaches learning through the understanding that learning should be spontaneous and student-driven (Škoda et al., 2015).

According to the constructivist view, collaboration involving active problem solving is also important to learning. Students learn through interaction with the learning material, environment, teachers, and other students. Therefore, it is also important that students work collectively to solve problems that have real-world relevance. Active learning strategies such as collaborative problem-solving encourage student engagement through the application of science (Mansour, 2009). When students work collaboratively there is little to no interruption from the teacher, who is seen more as a facilitator in the classroom. The importance of the social environment on learning is illustrated in Vygotsky's theory of constructivism which asserts that students need to interact with each other in order for learning to be effective (Kugelmass, 2007). This student-centered approach to science education illustrates the main components of a flipped classroom.

Although constructivism is not a teaching method; it is a theory of learning that informs many inquiry-based pedagogies. The core assertion in constructivism is that learning is an active process and knowledge is subjective and personal. Learning occurs through one's interaction with new information and is subject to interpretation based on individual experience (Khan, 2013). In STEM academic areas the constructivist theory of learning is appropriate as students are expected to be innovative and creative in finding solutions to problems.

According to Vygotsky's social learning theory, learning is dependent on the social context. In the flipped classroom the environment is conducive for learning by allowing students to engage in collaborative problem solving and thoughtful discussion. Discussion-based learning also provides immediate formative feedback to students which helps to eliminate misconceptions about the content (Mavromihales & Holmes, 2016). Additionally, students are able to acquire through practice the higher order thinking skills outlined by Bloom's taxonomy which include analysis, evaluation, creation, and application. The traditional lecture approach typically only allows students to demonstrate lower order thinking skills such as memorization.

The constructivist theory provides a general framework that informs specific aspects of learning, all of which are important components in creating an environment conducive for learning. Specific aspects of learning include inquiry, cooperation and collaboration among students, student involvement theory, and cognitive theory. Each of these subcategories of constructivism are described in the following subsections.

Cooperative Learning Theory

Cooperative learning is a teaching strategy rooted in social constructivism. This strategy allows students to work collectively in small groups on active learning tasks. The theoretical idea behind this approach is that by allowing students to engage in peer collaboration the student's understanding of science content and skills are improved. Chang and Mao (1999) conducted a comprehensive study of 16 earth science classrooms in Taiwan. These researchers assessed various outcomes associated with academic engagement and achievement and compared these outcomes between traditional lecture classrooms and inquiry-based classrooms. The results of the study showed that the students in the inquiry-based classroom scored significantly higher on the Earth Science Achievement Test compared to students in the control group. Furthermore, the students in the inquiry classrooms showed significantly higher positive attitudes toward the course content and curriculum. These findings support other research that indicates an inquiry-based approach in the science classrooms increases student engagement and achievement. These findings combined with previous research on flipped classroom instruction and best practices provide a strong indication that flipped classrooms are more effective than traditional lecture approaches due to the emphasis of inquiry and collaboration (Chang & Mao, 1999; Clark, 2015; Overmyer, 2015).

Inquiry Approach

Science instruction and the design of learning environments for science instruction tend to focus on two theoretical frameworks: constructivism and inquiry. Inquiry methods stress the importance of engaging students in activities that reflect the actual skills required to be effective scientists while Constructivism focuses on a tailored environment that is conducive for inquiry and thus, learning (Wagh et al., 2017).

Inquiry in education is a student-centered approach to learning. The inquiry pedagogy focuses on designing learning experiences that lead to active construction of knowledge by the student. This active construction stems from problem solving, information gathering, design, discussion and collaboration with peers (Barrow, 2006). In this way, the inquiry approach is rooted in constructivism and social learning theory. The strategies employed in the inquiry-based classroom guide the student toward higher levels of cognitive functioning and allow the student to think in a constructive way rather than memorize facts or figures. In a science classroom, these skills are particularly important. According to the principles of pragmatism, students gain knowledge through practical work and experimentation. Thus, the student's experience and interaction with both the material and the student's peers are paramount in the learning process (Wagh et al., 2017).

Student Involvement Theory

The student involvement theory was a framework for educators to design more effective learning environments. The basis of the theory is that student academic achievement is directly linked to the way students spend their time and energy on both academic and social pursuits (McCallum et al., 2015). Both the academic and social aspects of education are important in the learning process, according to this theory. This theoretical framework is similar to the ideals of constructivism in that learning occurs best as a social activity and not in isolation.

Student involvement and student engagement are directly linked, and both contribute to the efficacy of the flipped approach. By its very nature, the flipped approach encourages students to apply a measure of self-regulation and self-discipline in order to be successful. In the flipped classroom, students must access and interact with course content outside of class time. These students are no longer able to be passive recipients of knowledge through listening to a lecture. Rather, they must engage with the material before coming to class and then apply the content in meaningful ways. The application of the material is often done through problem solving or peer collaboration. The teacher in the flipped classroom must be skilled at providing experiences that engage and challenge students. Additionally, the flipped approach provides a framework for students to monitor their own learning and increase self-regulation (Lai & Hwang, 2016).

Self-regulated learning contributes to academic achievement in several ways. According to Zimmerman (as cited in Lai & Hwang, 2016), there are three stages to successful self-regulated learning: forethought stage, performance, and self-reflection. During the forethought stage students analyze the learning objectives and set goals and strategies that are specifically aligned to the learning objectives. The implementation of said strategies occurs during the performance stage and is accompanied by student self-monitoring. Finally, during self-reflection, students assess the efficacy of the learning strategies in an effort to evaluate if their goals were met. The use of technology makes self-regulation very easy to apply and facilitates active learning. Furthermore, students that can apply self-regulation will be more successful in a flipped classroom.

Cognitive Theory of Learning Involving Working Memory

Learning involves changing the neural pathways of the brain to create an efficient system of interaction between our working memory, short-term memory, and long-term memory. Research shows that effective learning occurs when dual coding occurs. That is, the activation of both the visual-pictorial and auditory-verbal systems when information is encoded leads to more effective learning results (Foster et al., 2016). In a traditional lecture classroom, the students are primarily activating the auditory and visual systems through a passive learning approach. A flipped approach creates an environment where students have meaningful experiences that contribute to shaping their understanding of the course material. Furthermore, students are engaged in active learning where multiple sensory processing systems are active which leads to more effective learning outcomes.

Students in the flipped classroom are able to practice the application of skills more often than during a lecture classroom. The strategies involved with students working collaboratively or independently to practice problem-solving further strengthens neural pathways (Foster et al., 2016). In a traditional lecture class, students practice problems and the application of concepts through homework which they complete independently. However, in the flipped classroom the instructor can provide guidance when necessary and allow students to work collaboratively which contributes to an active learning environment. In terms of assessment, the flipped approach also facilitates more regular and immediate feedback to students which in turn creates an effective learning environment.

Abeysekera and Dawson (2015) suggested that the lecture approach is not effective in teaching critical thinking skills, which are essential for successful science education. However, these researchers point out that in the flipped classroom, through self-paced learning strategies, cognitive load demands on working memory are minimized.

Constructivist Theory Summary

The constructivist theory assumes that students learn best when actively engaged in activities that promote inquiry, problem-solving, and collaboration. The social environment is just as important as the manner in which information and content are presented to the learner. Student involvement and student engagement are important components that facilitate the learner's construction of knowledge and allow the student to apply the knowledge in novel ways. For these reasons, the flipped approach may be more effective at promoting the skills associated with higher level mathematics and science because students are able to make connections between the content and real-world applications. As students are able to access lecture content outside of the classroom this leaves more time during class for collaboration and facilitated problem-solving. Additionally, the demands on a student's working memory are minimized in the flipped approach which may alleviate stress for students learning complex concepts, especially mathematical concepts, and in turn strengthen student motivation and engagement (Logie, 2018).

Student Engagement in the Flipped Classroom

Clark (2015) examined the efficacy of flipped instruction on achievement in a high school Algebra course compared to traditional lecture. Both qualitative and quantitative aspects of the learning process were indicated to benefit from a flipped approach. Specifically, students indicated that their level of engagement with both the material and other students improved in the flipped classes where collaboration and inquiry were emphasized over passive lecture strategies. Similarly, a survey of 60 mathematics students indicated that satisfaction and engagement were higher in flipped classrooms compared to traditional lecture. Additionally, these students noted that collaboration and inquiry were key components that increased their engagement in these flipped courses (McCallum, 2015). Similar results were noted in a pilot study conducted by Prashar (2015) in which students indicated a strong preference for the flipped approach over traditional lecture formats. Specifically, the researchers noted that student involvement, task orientation, innovation, and collaboration all increased using a flipped approach.

The motivation to apply a flipped pedagogy for STEM courses is rooted in the research literature that shows that positive effects on students and learning arise from an inquiry approach. In a traditional classroom environment where lecture is the main teaching strategy; students tend to focus on lower order cognitive thinking skills. However, in a flipped classroom the main teaching strategy is inquiry (Anderson & Brennan, 2015). In these classrooms, students gain higher order thinking skills by practicing and collaborating on problem-solving with peers. The level of interaction with both the course content and other students is significantly higher in a flipped learning environment. For this reason, educators have become increasingly motivated to employ these techniques in an effort to increase student engagement and achievement in STEM courses.

Flipped Classroom and Inquiry

Flipped classroom instruction has been associated with IBL. IBL has shown to be an effective tool for education in STEM areas. IBL strategies can be implemented through the adoption of the flipped classroom model. The flipped classroom reverses the traditional components of a classroom: direct instruction or lecture and homework assignments or practice work. In the flipped model the active learning component involving practice is done in the classroom where peer-collaboration and instructor guidance can facilitate and enhance the learning experience. Direct instruction and lectures are still an important part of learning but occur outside of the classroom through videos, websites, books, or other resources.

Although definitions of IBL can vary there are similar key components that include active participation of the students, student engagement with the learning environment and material, and collaboration with peers and instructors. According to Love et al. (2015), in a flipped classroom student-centered activities comprise roughly 60% of the classroom time. Whereas, in a traditional classroom the majority of class time is spent on passive learning such as students listening to a lecture.

Mazur et al. (2015) found support for the use of instructional techniques used in flipped classrooms in maximizing active student engagement and learning. These researchers noted that the flipped classroom is particularly conducive to an inquiry-based learning model which is effective for increasing achievement in a science or mathematics course. When students are active participants their motivation and curiosity is often increased. The flipped approach facilitates this by delaying direct instruction until students have had time to explore the content, make inquiries, and collaborate with peers (Ash, 2012).

Impact of IBSE

Effective learning strategies are those that encourage students to actively engage with the material and content that they are learning. Student involvement is a strong indicator of academic success in a particular subject (McCallum, 2015). If students are not interested or motivated, they will not engage with the material and therefore, will not learn. There is often more appeal for students when technology is used to deliver the content, especially in a STEM classroom.

Studies have shown that student achievement and comprehension of concepts in STEM courses increases when an active learning approach is utilized in classrooms. Traditional lectures, in comparison, seem to contribute to low levels of conceptual understanding and ability to apply important concepts to solve problems (Capaldi, 2015). These types of results are consistent across studies even when other variables are controlled for, such as, class size and instructor experience. IBL as a method, encourages student collaboration, communication, and discovery. In essence, IBL encourages curiosity by emphasizing active learning. This approach leads to higher critical thinking skills that are necessary for success in a STEM related academic area or profession.

Flipped classroom instruction has also been shown to increase student outcomes on conceptual understanding for mathematics. The Calculus Concept Inventory (CCI) is a widely used test for assessing student understanding of Calculus concepts and does not include a computation component. Similar tests are used in other STEM academic areas, namely physics. The Force Concept Inventory (FCI) and the Mechanics Diagnostic Test (MDT) each assess conceptual understanding in physics. Conceptual understanding for these academic areas is often overlooked in favor of computational proficiency in many traditional lecture classrooms. However, studies indicate that classroom strategies that include interactive engagement show higher improvement for students taking these courses compared to traditional methods (Epstein, 2013). Interestingly, on tests of basic skills there appears to be little difference in performance based on instructional practice. However, for tests of conceptual understanding and critical thinking, the students in classrooms that use engagement strategies typically employed in a flipped classroom have a distinct and significant advantage over learners in a traditional environment (Schoenfeld, 2002). These findings have strong implications for best teaching practices in the areas of STEM academics.

Meta-Analysis

Techniques

Meta-analytic techniques can be applied to research across a diverse range of disciplinary fields. In the field of education, meta-analysis can help educators understand the effect of a particular pedagogy on academic achievement. A meta-analysis can help to answer questions regarding consistency of effect across a wide variety of research studies. A meta-analysis may also be used to determine, when effect size is inconsistent across studies, how much variation occurs and whether certain factors may contribute to the variation. Using this approach requires that effect sizes be calculated for individual studies in order to compute a summary effect. As each study varies in regards to sample size and given *p*-values, the precision of each study is accounted for by assigning an appropriate weight to each individual effect size before computing an overall summary effect (Borenstein et al., 2009).

In basic terms, a meta-analysis is a technique that allows for results of similar studies to be synthesized in order to identify the overall cumulative effects in a particular field of research. Although, meta-analysis has become common in medical and clinical research it is an appropriate tool to apply when informing evidenced-based practices in education (Higgins & Katsipataki, 2016). The overall process of a meta-analysis involves gathering a sample of research studies that have been evaluated according to predetermined inclusion and exclusion criteria. Typically, this information is reviewed and coded prior to analysis. Choosing an appropriate effect size is of particular importance when conducting a meta-analysis and the decision should be driven by three main considerations. The first consideration involves evaluating whether the studies in the analysis measure the same outcome, at least in an approximate manner. Secondly, effect sizes should be computable from the given data in each individual study. The data needed to compute an effect size is likely included in published research studies but this is not always the case. Lastly, the sampling distribution should be known in order for variances and confidence intervals to be computed (Borenstein et al., 2009).

Benefits

The main currency of a meta-analysis is the effect size of each study rather than a *p*-value. The advantage of using the effect size is that it allows for the computation and evaluating of a summary effect. Using effect sizes, the dispersion of effects can also be assessed. However, in a narrative review, the main currency of evaluation is the *p*-value which offers no method of statistical evaluation when combining individual studies (Borenstein et al., 2009). Although a meta-analysis only requires two or more eligible studies there are typically many more studies synthesized into a summary effect. Therefore, another advantage of meta-analysis is that the technique allows researchers to deal with a large quantity of information and develop practices that are truly evidenced-based and more likely to generalize to the population (Higgins & Katsipataki, 2016). In education research, the studies involved often have small sample sizes and consequently yield moderate or low effects. When a researcher looks at just the statistical significance of each individual study they may be misled regarding the effectiveness of a particular treatment.

Aside from enhanced statistical exactness, another advantage of meta-analysis is that the results may be replicated. A systematic review is subject to researcher bias and interpretation and therefore, not reproducible. In a meta-analysis, the same data should yield the same summary effect, although different weights may be applied to studies depending on precision criteria that is applied (Reinard, 2006).

Limitations

As with any statistical methods, there are limitations to the design and implementation of meta-analytic techniques. One of the critiques of meta-analysis is that the technique is limited to quantitative research studies which may limit the researcher's ability to reach conclusions based on theoretic or conceptual arguments. With a meta-analysis, the researcher must clearly operationally define the particular outcomes that are to be examined. In order for the analysis to produce reliable and accurate summary, there must be an assumption that the studies are similar in outcome measures and how these measures are defined. Clarity of inclusion criteria and definitions are essential to avoid adding studies together that are not inherently comparable (Higgins & Katsipataki, 2016).

Additional criticism of meta-analysis stems from the methodology of incorporating individual effect sizes into a single effect summary statistic. Critics of this technique assert that this approach disregards individual study effect sizes. However, as noted by Borenstein et al. (2009) individual studies are weighted according to study precision in order to provide a synthesis which is more generalizable compared to the individual effect sizes reported in each study. Furthermore, it is common practice to provide a summary of individual effect sizes for readers to examine.

According to Reinard (2006), there is potential for studies to be included in a meta-analysis that do not reflect the exclusion and inclusion criteria set forth prior to conducting the analysis. If this is the case, the studies that are included may underrepresent or misrepresent the sample. This leads to the argument that meta-analysis is prone to the “garbage in” – “garbage-out” argument which basically states that the meta-analysis is only as good as the quality of studies included. This problem can be safeguarded against when the researcher clearly defines the outcome measures, inclusion criteria, and exclusion criteria.

Summary

According to the literature, the flipped classroom approach is a model that involves the traditional lecture component and homework component of a course to be reversed. Much of the research on flipped pedagogy has focused on assessing the efficacy of this approach on specific learning outcomes and gaining a better understanding of how flipping the classroom may enhance learning outcomes (Mavromihales & Holmes, 2016).

The purpose of this study was to provide an effect summary for studies that quantitatively compare flipped classrooms to traditional lecture classrooms on the outcome measure of academic achievement. Furthermore, the aim of this study was to examine the efficacy of the flipped approach for achievement in science, technology, engineering, and mathematics (STEM) courses. Brown (2012) provides several useful definitions of STEM, including one provided by the United States Department of Education in 2007. According to this department, STEM education refers to any program, at any grade level, that supports or strengthens science, technology, engineering, or mathematics. However, Merrill (2009) defines STEM as a meta-discipline that involves collaboration and integration among and between STEM teachers (as cited in Brown, 2012).

Research on STEM education employs a wide range of methods, outcomes, and population groups. The research has largely focused on qualitative and mixed methods approaches to provide descriptive information about populations, teaching methods, and various outcome measures. However, as noted by Brown (2012), there appears to be a lack of large-scale quantitative research on STEM education. This is likely due to research on specific classrooms where a finite number of students are present. A meta-analysis that examines the effects of flipped instruction for improving the outcomes in STEM classes provides a better measure of effect while maximizing statistical power.

There is a need for more effective teaching strategies in STEM academic areas. The traditional lecture pedagogy has been shown to be ineffective at promoting the higher order thinking skills needed to be successful in any STEM area. In order to develop evidenced based practices that will increase academic achievement and student motivation to increase the number of students that decide to major in a STEM discipline (Talley & Scherer, 2013). The flipped or inverted classroom has been shown to be effective at promoting STEM through the use of methods that involve active student participation, peer collaboration, inquiry, analysis, and innovation. However, implementation of the flipped classroom approach requires that teachers become skilled in creating quality experiences that promote active learning. This will likely require resources, support, and time. A meta-analysis that shows how effective the flipped approach actually is will help to inform educators about whether the benefits are worth the costs.

Although there are limitations to a meta-analysis, these limitations can be minimized by researchers by clearly defining inclusion and exclusion criteria as well as consideration of heterogeneity of effects. Careful review of literature ensures transparency safeguards against potential bias. When done correctly, meta-analyses can be used to provide the most informative and comprehensive effect size information.

Chapter 3: Research Method

Introduction

The flipped classroom design is not new to the education system, although the terminology has gained more momentum in recent years. Flipped or inverted classrooms involve the practice of switching homework and lectures. This allows students to engage in passive learning efforts at home while keeping actively engaged in the classroom (Hall & Dufrene, 2016). The flipped approach is becoming a movement among educators who seek to instill 21st century skills in students such as critical thinking and analysis and problem-solving.

Although flipped classrooms have gained popularity, and there is evidence that students in these classrooms reach higher achievement levels compared to traditional lectures, there is variability in terms of implementation of this pedagogy. These variations make it difficult for researchers and educators to ascertain how effective flipped classrooms actually are, and whether they are cost-effective instructional strategies. I sought to answer the following research question and subquestions:

RQ1: To what extent do standardized achievement test scores in terms of meta-data of flipped and traditional classrooms differ?

SQ1: What is the range of effect sizes, including 95% confidence intervals, for flipped-class instruction in STEM courses?

SQ2: What is the overall mean effect size for academic achievement in flipped classroom strategies, including 95% confidence intervals, when compared to traditional lecture strategies?

SQ3: Do effect sizes from individual studies differ from the overall mean effect size based on particular moderator variables, such as academic subject, student population, experience of teacher, or other demographic variables?

Education is important, especially in STEM academic areas, in terms of promoting scientific literacy and enabling generations of students to effect positive social change through innovation. Thus, answering these specific research questions will allow educators and administrators to make informed decisions regarding best educational practices. Results of this proposed study will either support flipped classroom pedagogies as a means of increasing academic achievement for students in STEM classes or show a lack of support.

Research Design and Rationale

I used a quantitative meta-analytic technique to answer the research questions. For the purpose of this study, a quantitative approach with the predictor variable flipped classroom instruction and dependent variable academic achievement was used. I synthesized current literature regarding effects of the flipped approach compared to the traditional lecture approach in order to provide educators and students with a better understanding of effective teaching strategies.

Meta-analysis refers to statistical methods that are applied to synthesize quantitative research studies for the purpose of obtaining an overall effect size of a variable in question (Ghahramanlou-Holloway, 2007). Statistical significance, being closely tied to sample size, does not always indicate a true effect for a particular treatment or intervention. Since sample size and other variations in methodology and population can impact statistical significance of a particular study, it is advantageous to apply a meta-analytic approach to aggregate the current body of literature and calculate an overall effect size. Through the method of calculating weighted averages for each studies' effect size and creating a forest plot, a true effect size may be obtained.

This proposed meta-analysis study involves informing educators about the effectiveness of applying a flipped classroom pedagogy in STEM academic classrooms. Flipped or inverted classrooms have been compared quantitatively to traditional lecture pedagogies in many research studies. Generally speaking, results of these studies seem to indicate that the flipped approach leads to higher academic achievement compared to traditional lectures. However, statistical significance and effect sizes of each study vary due to differences in sample sizes and other variables. A meta-analysis was necessary to provide educators with information necessary to make informed decisions regarding best teaching practices.

Methodology

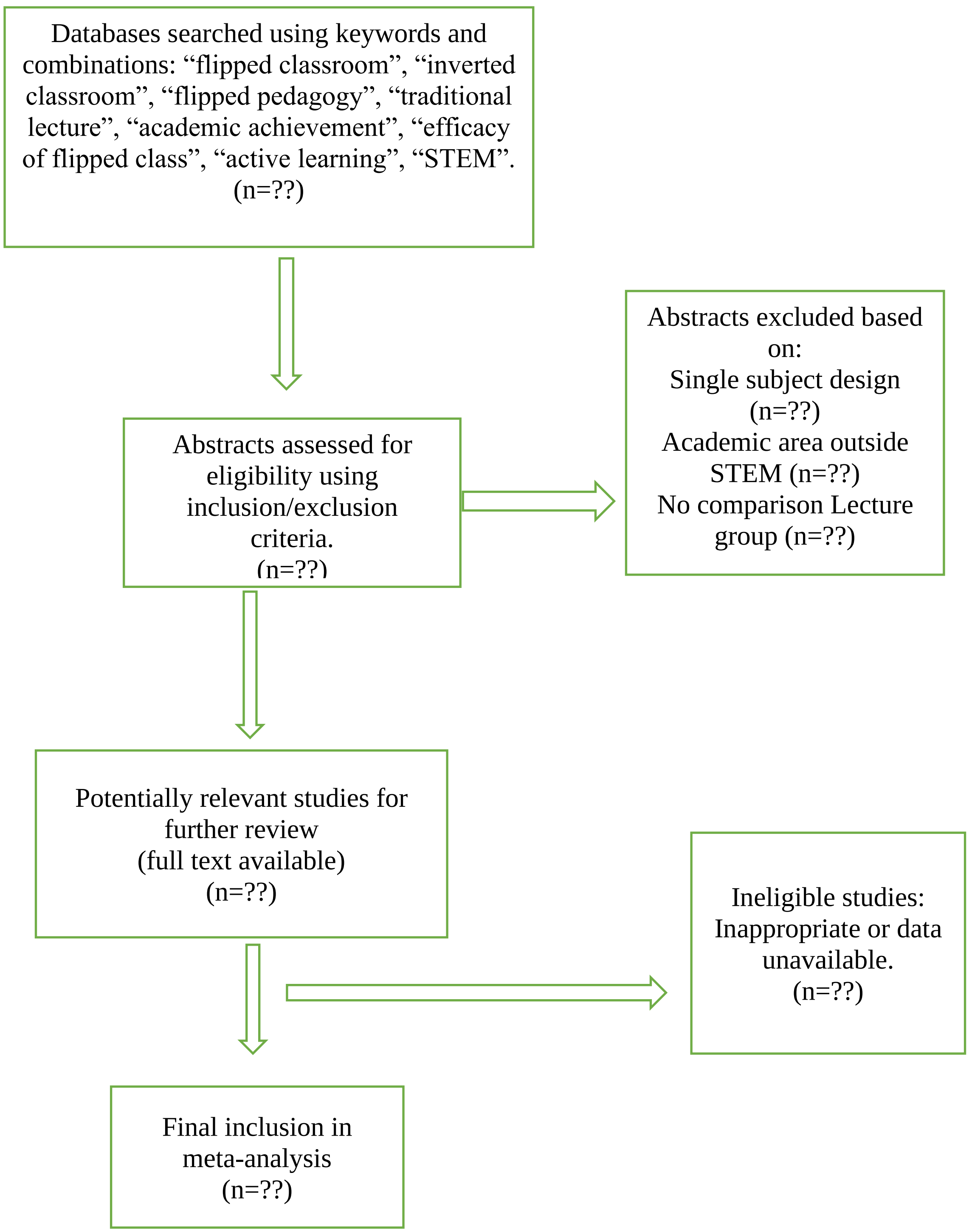
Selection Criteria

I used a systematic process that began with a review of abstracts from databases in order to find as many studies as possible that were quantitative and addressed the main issue of flipped classroom efficacy. Qualitative studies or studies that did not include enough data for computing effect sizes were excluded from the meta-analysis but retained for interpretation of findings (see Figure 1).

Studies that involve comparing flipped classroom instruction to traditional lectures in terms of outcome measures of academic achievement were identified through a search of electronic databases using the following keywords: *flipped class**, *inverted class**, *lecture-based instruction*, *lecture pedagogy*, *flipped pedagogy*, *academic achievement*, and *STEM*. The following databases were searched for applicable studies: Academic Search Complete, Education Source, ERIC, LearnTechLib, Teacher Reference Center, ScienceDirect, SAGE Journals, Taylor and Francis Online, ProQuest Central, PsycINFO, SocINDEX, and PsycARTICLES.

Figure 1

Meta-Analysis Flow Chart



Following the initial search and collection of potential studies, abstracts were reviewed for inclusion and extrusion criteria. The inclusion criteria included the study being quantitative, using academic achievement as an outcome variable, comparison of flipped learning to lecture-based approaches, studies that focused on STEM related academic disciplines, and data that could be used to compute effect size and weighted means. The exclusion criteria include qualitative studies, studies that focused on academic areas outside of STEM disciplines, dissertations, and duplicate studies. Additionally, a review of citations included in relevant studies yielded additional research studies that werenot found through the search of electronic databases. These studies were reviewed using the inclusion and exclusion criteria previously described. Any studies that did not include statistical information necessary to compute an effect size or studies that did not include a sample size were also excluded. All remaining studies were then organized for data extraction.

Data Extraction

Once a sample of eligible studies was identified, each study was hand coded by study characteristics. The categories used for coding of the research studies were based on prior literature review as well as the nature of the proposed research study. The first set of characteristics that were coded were the study identifiers which included the study ID and reference information. All moderating variables were coded as well as a code indicating the characteristics of study quality. Studies of the efficacy of flipped classroom pedagogy on increasing academic achievement utilize various methodologies and populations. Therefore, population, methodology, and academic subject were included as potential moderating variables. The overall design of the study was coded by recording information regarding assignment of subjects to groups and the experimental design. In addition, for each study, the method of calculating effect size was included in the coding process. During the process of coding research studies, it is natural for the codes to evolve to accommodate new information, methodology, or moderators. Coding the studies initially by hand and then entering them into an analysis software helps to ensure that coder-drift does not occur and compromise the reliability of the meta-analysis (Whiston & Peiwei, 2011). Initial coding was done by hand and later entered into the analysis software.

Data Analysis Plan

Data analysis was conducted using the statistical software, OpenMeta[Analyst], provided through the Brown University website free of charge. OpenMeta[Analyst] facilitates the statistical analysis necessary for a systematic meta-analytic review by computing individual study effect sizes and presentation of graphical results via forest plots. In addition, studies can be coded for characteristics and moderators through the software.

Effect Size Calculation and Statistical Procedures

For studies that report means and standard deviations, effect size can be determined by calculating the standardized mean difference. In studies that compare groups on a continuous dependent variable, this information is usually reported (Deeks & Higgins, 2010). The equation for calculating the standardized mean difference is as follows:

$$SMD = \frac{Difference\ in\ mean\ outcome\ between\ groups}{Standard\ Deviation\ of\ outcome\ among\ participants}$$

Although the standardized mean difference is the appropriate measure of effect size when the means can be calculated, it was necessary to use alternate methods of effect size computation when the statistic reported was a *t*-test or correlation study.

OpenMeta[Analyst] software compute effect size using Hedges' (adjusted) *g* and is thus calculated using the following:

$$SMD_i = \frac{m_{1i} - m_{2i}}{s_i}\left(1 - \frac{3}{4N_i - 9}\right)$$

$$\mathrm{SE}\{SMD_i\} = \sqrt{\frac{N_i}{n_{1i}n_{2i}} + \frac{SMD_i^2}{2(N_i - 3.94)}}$$

Once the effect size had been computed for each study in the sample, preliminary transformations were necessary to correct for small sample bias. Following these considerations, the standard error was computed to determine the inverse variance weights to assign to each study. Using OpenMeta[Analyst] with the assumption of a random-effects model with weighted effect sizes a combined result was calculated. The calculation included a 95% confidence interval, and a forest plot of individual studies' mean standardized effect for academic achievement in a flipped pedagogy was produced.

Summary of Statistical Calculations

The steps and equations used are:

Adjustments to Data:

1) Calculate standardized mean differences (*d*), if necessary

$$\text{Cohen's } d = \frac{M1-M2}{SD\ pooled}$$

$$\text{Where } SD \text{ pooled}=\sqrt{\frac{(SD_1^2 + SD_2^2)}{2}}$$

2) Calculate standardized mean differences (*d*) from correlation coefficient (*r*), if necessary

$$d = \frac{2r}{\sqrt{1-r^2}}$$

3) Calculate a standardized mean difference (*d*) using *t*-stats and sample size, if necessary

$$d = \frac{t(n1+n2)}{\sqrt{(n1+n2-2)(n1n2)}}$$

If sample sizes are equal (*n1* = *n2*), the previous equation reduces to

$$d = \frac{2t}{\sqrt{(df)}}$$

Random-Effects Model:

4) Calculate the between-studies variance

$$T^2 = \frac{Q-df}{C}$$

Heterogeneity Analysis

Although a random-effects model makes the assumption that the effects in the proposed study are not identical but rather follow a similar distribution; heterogeneity should still be a consideration. Using OpenMeta[Analyst] software allows for an estimate of the between-study variance through tau-squared (τ^2 or Tau^2) in addition to the estimated standard deviation. The confidence intervals in a random-effects meta-analysis model do not describe the degree of heterogeneity among studies but provide an estimate of uncertainty (Higgins & Green, 2011).

Moderator Analysis

Following an initial comparison of the overall effect mean effect size, moderator analyses can be conducted to analyze trends or patterns that emerge from the data. There may be differences in effect between flipped classrooms and traditional lecture pedagogies that stem from the academic discipline in question, teacher experience, student demographics, or even geographical location. It is difficult to anticipate which moderators may show an overall effect prior to conducting the meta-analysis. Consequently, it is impossible to know how many post-hoc analyses may be conducted in the proposed research study.

Threats to Validity

Threats to validity in a quantitative research study may include internal threats or external threats, which refer to the generalizability of the outcome variable in question. The goal of meta-analysis is to summarize the results across multiple studies to obtain an overall mean effect size. This method of analysis relies on the assumption that the results of individual studies were relatively free of methodological errors. Studies that were riddled with methodological flaws were excluded from the analysis as a safeguard against the threat to the validity of the study. Borenstein et al. (2009) describe statistical measures to correct effect size estimates to eliminate or reduce these inherent methodological errors. Methodological problems in an individual study may stem from a finite sample size or from measurement error (imperfect reliability). Studies that used continuous outcome measures such as correlation coefficients or standardized mean differences used effect sizes that were standardized which resulted in a restricted variance or range of possible outcomes. This led to reduced effect size but was corrected by comparing the observed (unadjusted) effect size to the true (adjusted) effect size through a ratio which is referred to as the artifact multiplier (Borenstein et al., 2009).

Threats to Reliability

The reliability of the meta-analysis is a measure of the consistency of the coding system used to detail each study included in the analysis. Low reliability of the coding system results in additional variability of measurement. Mathematically, the reliability of the coding system takes the following computational form:

$$\frac{Variability\ of\ idealized\ \text{true}\ scores}{Variability\ of\ measured\ scores}$$

The use of statistical software can assist coding by storing information in an organized way. This simplifies the coding process and facilitates agreement if the same study is coded multiple times. Clear operational definitions of each code used and reporting the inter-rater reliability are additional safeguards against threats to the reliability of the study. When one researcher codes each study twice using the same standard coding categories an Agreement Ratio (*AR*) can be computed to estimate the internal reliability. The higher the Agreement Ratio, the more reliable the process. The computation is as follows:

$$AR = \frac{Number\ of\ Agreements}{Number\ of\ Studies}$$

Ethical Procedures

This research study utilized secondary data rather than individual participants. As such, there were no ethical considerations to be made regarding treatment of participants. The raw data, consisting of published and un-published research studies, was coded and analyzed using meta-analytic statistical methods.

Summary

This study involved determining an overall effect size for research on academic achievement in flipped classrooms compared to traditional lecture approaches by applying a meta-analytic methodology. This study excludes academic areas outside of STEM disciplines but includes a wide range of populations, geographic locations, and implementation strategies.

This study consisted of a systematic review of literature that met specific inclusion and exclusion criteria. Systematic coding of characteristic variables occurred for each study in order to extract information that was necessary for calculating effect size and analysis of moderator variables. For the purposes of this study, a coding manual was created and followed (see Appendix A). Proposed coding variables, which evolved during meta-analysis, included study sample characteristics, design characteristics, academic subject area, achievement measures, study quality, implementation characteristics, and results. Coding of study characteristics was ultimately managed using Review Manager software.

Following the data extraction process, data were analyzed and adjusted for biases. A calculation of effect size including adjustments for sample size was computed to obtain weighted standardized effect sizes. Qualitative evaluations were also made regarding the design of each study, and assumptions were made after effect sizes were combined. As in most meta-analyses, a 95% confidence interval for each study's standardized mean effect was used for information presented via a forest plot. Combined effect sizes demonstrated heterogeneity which warranted the use of a random-effects model.

Chapter 4: Results

Introduction

This literature review involved studies that examine benefits and challenges of implementing a flipped pedagogy. These studies vary in terms of their methodologies and in populations of participants. Additionally, these studies vary in terms of how a flipped classroom is defined. These variations along with small sample sizes make it difficult to discern whether the flipped approach provides a learning framework that significantly improves academic outcomes compared to more traditional methods. Using a meta-analysis allows for studies with similar outcomes to be combined in order to determine a more accurate effect size, even if sample sizes vary considerably. As described in Chapter 1, the goal of my research was to address the following research question and subquestions:

RQ1: To what extent do standardized achievement test scores in terms of meta-data of flipped and traditional classrooms differ?

SQ1: What is the range of effect sizes, including 95% confidence intervals, for flipped-class instruction in STEM courses?

SQ2: What is the overall mean effect size for academic achievement in flipped classroom strategies, including 95% confidence intervals, when compared to traditional lecture strategies?

SQ3: Do effect sizes from individual studies differ from the overall mean effect size based on particular moderator variables, such as academic subject, student population, experience of teacher, or other demographic variables?

Data Collection

In a meta-analysis, participants are research studies. Collectively, these studies comprised my sample. Therefore, recruitment and response rates were not a concern.

I aimed at examining the efficacy of flipped classroom instruction for STEM academics only. As such, participants were students enrolled in courses in STEM fields. Studies included high school through undergraduate level participants. Due to how outcomes were measured, I decided to exclude any studies that focused on elementary level instruction.

Additionally, studies that were included compared traditional lecture teaching approaches to the flipped classroom approach. The flipped classroom approach was defined as flipping active and passive learning components of courses. Noncomparison studies were excluded from this meta-analysis.

Studies were collected over a period of 6 months via a thorough search of available databases. A systematic review was used to incorporate studies that inherently contained variability. Heterogeneity among studies must be considered when conducting a meta-analysis, especially when given a small set of studies to. When there is variability in terms of participants, interventions, and outcomes, there may be clinical heterogeneity. Studies included in this meta-analysis involved using similar outcome measures of academic achievement. Both clinical and methodological heterogeneity introduce bias in meta-analyses (Higgins et al., 2020). However, in this study, participants evaluated outcomes associated with flipped classrooms in comparison a traditional lecture classrooms which minimize heterogeneity. Additionally, all studies involved STEM-specific academics and using outcome measures that focused on achievement in academic courses.

Results

Study Characteristics of STEM Academics

This meta-analysis included 15 candidate studies that ranged in sample size from 32 to 579, with a total of 2,018 participants. Studies were published between 2013 and 2019, and one study was included twice as researchers tested two separate samples of college students in the fall and spring semesters. Each study used quantitative methods to compare academic achievement between traditional lecture and flipped teaching approaches. A variety of effect sizes were reported in findings of individual studies. Additionally, studies involved factors such as teacher experience, academic area, technology use, quality of instructional models, and prior knowledge and skills of students.

Most participants (61%) in candidate studies were in mathematics courses, while science and engineering courses comprised 19% and 15%, respectively. Participants in technology courses made up the remaining 5%. All studies were conducted at college campuses with undergraduate participants with similar demographics.

Variability in Execution of Flipped Classrooms

Flipped learning is an approach that moves types of direct instruction such as traditional lectures out of the classroom. The lecture component becomes homework that students must complete outside of class time. Classroom time then becomes dynamic and interactive, as well as more engaging for the student. Each study included in this meta-analysis defined the flipped classroom in essentially the same terms: active learning components (homework) and passive learning components (lectures) are switched. Additionally, studies included in this meta-analysis measured the same outcome of academic achievement.

Execution of the flipped approach can vary considerably. Some classrooms completely flipped their courses, transferring all lecture materials online and relying on students to watch and take notes in preparation for active components during live class time. Other classrooms employed a less intense version of flipping, opting instead to have most or some lectures transmitted to students outside of class time that are supplemented by minilectures during class.

Variability, in terms of execution of flipped classrooms, involves quality of videos and lecture materials, student and teacher experience with these environments, and ratio of flipped and traditional components in the classroom. Anderson and Brennan (2015) opted to have students watch videos in advance of class and complete short online homework assessments based on material presented in the videos, and then students engaged in group discussion and problem-solving in class with instructors present to facilitate and lead short impromptu lectures as needed.

Outcome Metrics Assessments

In educational programs, it is common for instructors to use both formative and summative assessments during their evaluations of student learning and academic achievement. Formative assessments allow for real-time feedback that students use to improve upon their work and ultimately their understanding of the material. Formative assessments are tools that help shape the direction and pace of student learning. Summative assessments typically happen after learning has occurred. While both types of assessments are essential for the overall learning process, summative assessments involve measure academic achievement in a manner that is relevant to this meta-analysis. The objective of this meta-analysis was to provide a true effect size involving efficacy of flipped compared to lecture approaches.

Some of the candidate studies (see Harrington et al., 2015; Lee, 2006; Talley & Scherer, 2013) measured student achievement based on several different metrics that included both qualitative and quantitative methods. Harrington et al. (2015) tested students on knowledge acquisition and content application separately and several times throughout the course. These researchers also provided data on formative assessments that included quizzes and papers. For this meta-analysis, data from test three that assessed knowledge and acquisition at the end of the course was included in the meta-analysis because this metric was most closely aligned with the definition of the measured outcome of academic achievement.

Data Manipulation and Statistical Model

A fixed-effect model assumes that the true effect size is the same in all participant studies. The studies used in this meta-analysis shared enough similar characteristics that the information can be synthesized. However, the studies were not identical; so, it was not reasonable to assume a fixed-effect model in this instance. The purpose of this study was to identify the impact of an educational intervention, flipped learning, on academic achievement. The effect size of the participant studies is likely to vary depending on a number of factors that may include: other resources available to the students, class size, age of students, teacher experience, and quality of the flipped paradigm implementation. Each of these factors could lead to fluctuations in the magnitude of effect size for an individual study. In order to address these variations a random-effects meta-analysis was utilized for this study. Using this model, it is assumed that the true effects are normally distributed.

This meta-analysis was conducted using OpenMeta[Analyst] software. OpenMeta[Analyst] is capable of estimating summary effect sizes and conducting heterogeneity tests for a random-effects model. Due to the software's built-in inverse-variance weighting, more accurate evaluations of relationships between moderators and effect sizes can be conducted (Wallace et al., 2017).

Excluded Candidate Studies

Several studies initially identified did not meet enough of the inclusion criteria to be included in the final meta-analysis. Excluded studies were analyzed and the results are reported in Table 1.

Table 1

Number of Candidate Studies Excluded by Reason

Insufficient data for effect sizes	Achievement outcome not measured	Non-STEM academic area
3	1	2

Studies were excluded based on the established criteria. Firstly, only studies that compared flipped pedagogy to traditional lecture approaches were included. Furthermore, only studies that focused on science, technology, engineering, and mathematics (STEM) academic areas were eligible for inclusion. Studies that utilized quantitative methods to compare the teaching pedagogies on the similar outcome of academic achievement were included, regardless of if the test was created for the purpose of the specific course or was a previously known measure of achievement. Studies that employed only qualitative methods were excluded from the meta-analysis. Studies that did not report statistical information necessary to calculate effect size or weighted effect sizes were also excluded.

Test of Homogeneity

According to Borenstein et al. (2009) a random effects model assumes that individual study effect sizes are sampled from a distribution of effect sizes. Using this assumption, study weights are more balanced using a random-effects model. Starting with a random-effects model, the homogeneity can be assessed by evaluating the heterogeneity a priori. The I^2 index quantifies the degree of heterogeneity in a meta-analysis by dividing the difference between the result of the Q test and its degrees of freedom by the Q value. This product is then multiplied by 100 to provide an easily interpreted percent of total variability due to true heterogeneity. An I^2 value that is low (below 50 %) indicates low heterogeneity and, therefore, high homogeneity.

The test for homogeneity in this meta-analysis indicated no homogeneity of effects, as was expected (Table 2). The Q statistic was a statistically significant value of 175.906 ($df = 14$), indicating a heterogeneous distribution. Additionally, the I^2 value was 97.082. Based on these results a random effects model was the appropriate choice for the current meta-analysis.

Table 2

Random Effects Meta-Analysis Results

Random effects model				
	95% CI			
Standardized mean difference	Lower	Upper	Standard error	*p*
0.399	-0.165	0.963	0.288	.166
		Heterogeneity		
Tau^2	Q (*df* = 14)	*p*	I^2	
1.179	175.906	< .001	97.082	

Hypothesis Analysis

Effect sizes, such as mean differences, can be evaluated by differentiating three size classes: small, medium, and large. A comparison of independent means may rely on effect size interpretations using Cohen's *d*, Hedge's *g*, or Glass. A small effect is given by 0.20, medium effects are 0.50, and large effects are 0.80 (Ellis, 2010). The weighted standard mean difference for the hypothesis of flipped pedagogy on academic achievement was 0.399 (95% CI: -0.165, 0.963). Using Cohen's criterion of effect size, this correlates with a small to medium effect.

Figure 2 shows the forest plot of standardized mean differences (flipped mean minus control mean) and weighted effect sizes. Table 3 contains study characteristics and statistics used in calculating the standardized mean difference. As evident in Figure 2 and detailed in Table 3 only one of the 15 studies had lower academic achievement scores for the flipped grouped. Of the 14 other studies, 11 had 95% CIs that indicated the flipped group had statistically significantly higher scores.

Figure 2

Forest Plot of Standardized Mean Differences and Weighted Effect Sizes

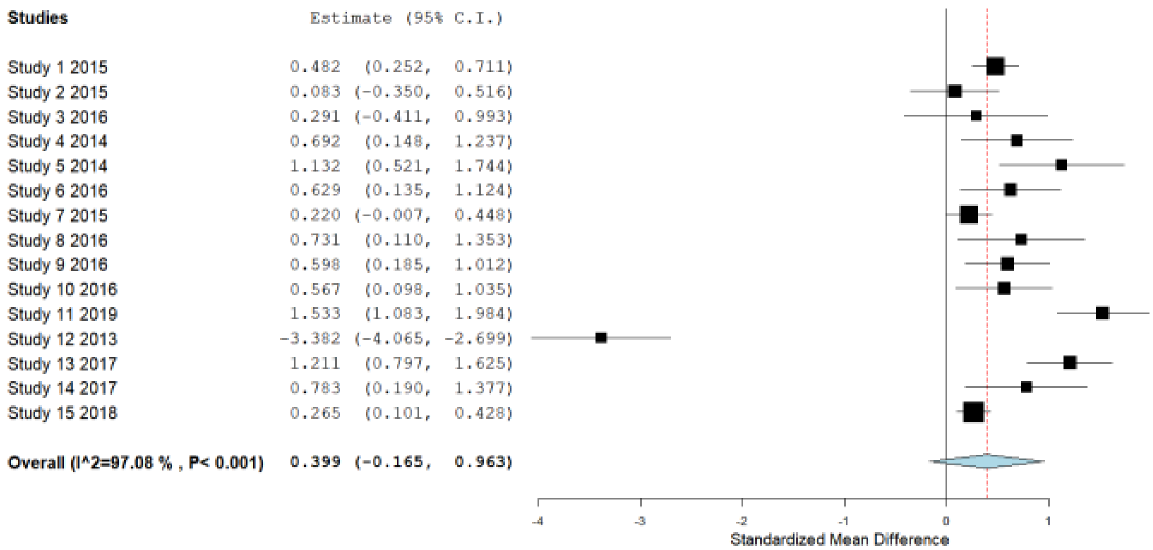


Table 3

Candidate Study Characteristics

Study #	Study	Year	Academic area	Flipped group (*n*)	Control group (*n*)	Flipped M (*SD*)	Control M (*SD*)	SMD[a]
1	Anderson and Brennan	2015	Engineering	126	186	69.10 (14.60)	61.00 (18.10)	0.482
2	Harrington et al.	2015	Nursing-Physiology	41	41	83.10 (5.40)	82.70 (4.00)	0.083
3	Lee	2006	Mathematics-Applied	18	14	9.17 (3.31)	8.21 (3.09)	0.291
4	Love	2004	Mathematics-Algebra	27	28	89.50 (2.99)	87.40 (2.99)	0.692
5	Mattis	2014	Nursing-Physiology	26	22	0.85 (0.16)	0.58 (0.30)	1.132
6	Murphy	2016	Mathematics-Algebra	32	34	101.00 (29.20)	82.40 (29.20)	0.629
7	Overmyer	2015	Mathematics-Algebra	136	165	21.27 (5.13)	20.14 (5.10)	0.220
8	Peterson	2016	Mathematics-Statistics	24	19	82.30 (14.30)	72.00 (13.20)	0.731
9	Sengel	2016	Technology-Computer Science	41	55	51.78 (11.33)	45.78 (8.78)	0.598
10	Singla	2016	Nursing-Physiology	38	35	18.58 (3.38)	16.65 (3.36)	0.567
11	Angadi et al.	2019	Medical-Physiology	49	49	15.53 (3.76)	9.61 (3.90)	1.533
12	Talley	2013	Physiology Psychology	40	40	62.88 (3.89)	74.51 (2.84)	-3.382
13	Collins Fall Semester	2017	Mathematics-Precalculus	52	54	33.77 (6.76)	25.06 (7.49)	1.211
14	Collins Spring Semester	2017	Mathematics-Precalculus	23	24	31.00 (6.01)	25.67 (7.28)	0.783
15	Carter	2018	Mathematics-General	284	295	54.00 (15.90)	49.80 (15.80)	0.265

Summary

The four principles of How People Learn (HPL) are learner-centered, knowledge-centered, assessment-centered, and community-centered. These core principles, when applied to a learning environment, transform the traditional lecture classroom into a flipped environment where learning is a collaborative effort and students are engaged (Geist et al., 2015). The flipped approach provides opportunities to practice flexible thinking while receiving immediate feedback. This allows students more freedom to take risks during the learning process and grow confidence in terms of their skill levels and abilities.

In this chapter, I reported results of this meta-analysis as well as a brief summary of findings. A small to medium overall effect size was found in terms of efficacy of flipped teaching compared to traditional lecture approaches. In addition, tests for homogeneity and heterogeneity reinforced use of a random effects model to obtain a true effect size. In Chapter 5, I summarize conclusions reached regarding findings of this study and explain the relationship between active learning approaches and overall academic achievement. Implications for social change and recommendations for future research are also discussed in Chapter 5.

Chapter 5: Discussion, Conclusions, and Recommendations

Introduction

I sought to obtain a true effect size for academic achievement in flipped classrooms. Addressing strategies and teaching styles that contribute to student achievement was a secondary goal which was pursued in qualitative terms. A meta-analysis combining 15 studies that each individually examined the efficacy of flipped instruction over traditional lectures in a STEM academic course was conducted. There is evidence that increasing student engagement leads to improved academic success for STEM courses. However, flipping a classroom is risky, as it is time-consuming and can be expensive. Knowing if outcomes are beneficial enough to warrant the considerable financial and time investment is important to make an informed decision about whether to flip. This chapter includes conclusions reached through this meta-analysis, as well as implications for social change and recommendations for future research.

The basic idea of a flipped pedagogy is to flip lectures with homework. In traditional terms, this implies moving passive learning components in which an instructor typically imparts knowledge and explains concepts while students listen and take notes, outside of face-to-face time. This frees this time with activities that provide students with a supportive environment in which to practice the application of learned conceptual knowledge. Media can be employed to deliver content to students (Sweet, 2014). Flipping a class is time-consuming, and educators new to the concept often find it to be a daunting task. While they may entertain the idea of flipping based on favorable literature, educators are reluctant to abandon traditional methods that have served them thus far, and are unwilling to devote time and resources to implement unfamiliar pedagogical approaches. Additionally, if it does not improve academic achievement, this wastes time and could have a negative impact on both educators and students.

Interpretation and Conclusions

Hypothesis Analysis

Literature frequently demonstrates the academic benefits of the flipped pedagogy, particularly in STEM classes. Researchers have often attributed efficacy of the flipped approach to increased motivation and engagement attained by students that allows them to become competent and confident problem solvers. However, studies that focus on achievement as an outcome and compare traditional approaches to the flipped approach often report slight or nonexistent effects. The aim of this research was to synthesize results from relevant comparison studies, all focused on STEM academic areas, to compute an overall effect size for the relationship between pedagogy and achievement. I addressed whether a flipped teaching approach significantly improves academic achievement for students in STEM classes compared to students in traditional lecture STEM classes. Additionally, I aimed to discover what factors, if any, might impact student achievement in STEM academics.

A meta-analysis of available data yields an overall effect size of the flipped approach on academic achievement weighted for a random effects model, which is small to medium. The standardized mean difference was 0.399 ($SE = 0.288$, $p = .166$). Results indicate that there was not a statistically significant difference in terms of effect size between the treatment (flipped class) and control (traditional class) groups, and therefore, the null hypothesis cannot be rejected. However, this was a loss of power due to the small number of studies that caused the effect to fall short of statistical significance.

Moreover, it is worth noting that only one of the 15 included studies showed a lower average achievement score for the flipped group. Talley and Sherer (2013) compared the flipped approach to traditional lecture approaches in a physiological psychology course and determined a significantly higher achievement effect for the traditional lecture approach compared to the flipped approach. Participants attended a historically African American college and had previously reported disliking biology and that they found science courses that were heavily mathematical to be more challenging than other psychology courses. Self-explanation and practice testing were found to improve average course grades for students in flipped courses as well as those not in these courses. Additionally, among African American STEM students, these learning techniques improved student retention.

The literature on flipped teaching is vast and encompasses both qualitative and quantitative studies. Qualitative research focus tends to involve teacher and student perceptions and attitudes regarding the flipped approach. Quantitative studies were focused on achievement in a particular field, or in some cases motivation and retention. Results were mixed among both types of research. Some students found the flipped approach to be beneficial as it provided them with more time during class to work out problems while an instructor was available to serve as a guide. Other students disliked the flipped approach because it required active participation and engagement during class time, and they preferred to passively take notes. Teacher reviews of this method are also mixed. While some teachers have great success implementing the flipped approach, others struggle to embrace shifts in roles from instructor to facilitator (Herreid & Schiller, 2013). Traditional teachers have always used lecture approaches, and without support are not interested in the investment needed to flip a class curriculum. However, in some STEM academic areas, the flipped approach is having a significant impact on achievement, motivation, and student retention.

It is necessary to examine confounding variables which include teacher experience and knowledge as well as amount of funding available for technology that is needed to successfully integrate flipped components. Future research could involve examining these variables in a more comprehensive manner; however, the preliminary literature review indicated there are some key flipped components that are most likely to promote academic achievement in a STEM course. Classrooms that were successful in terms of implementing quality video lectures and formative assessments ensured students accessed and watched videos in preparation for class time. Assessments are important motivators for students, especially when those who are grade-oriented (Ozan & Kincal, 2018).

Successful flipped classrooms engage with and motivate students through activities that are rewarding and intrinsically motivating. Problem-based inquiry activities that allow students to apply content in a collaborative manner are highly motivating, provided problems are not overly difficult. Flipped teachers must ensure students remain in the zone of proximal learning, and the most effective way to do this is ensure that students are prepared with content knowledge and presented with opportunities to apply that knowledge, with facilitation from an expert when necessary.

Exploratory Analysis

The goal of this meta-analysis was to ascertain a true effect size and not explain variations in effect sizes among the sample of studies. There were no subgroups or variables assessed for correlations with observed effect sizes. However, among the 15 studies, the test of heterogeneity yielded a large I^2 statistic of 97.082. As variability among studies was large, it would be worthwhile for future research on this topic to examine these differences. Future research that reports effect sizes in terms of geography, socioeconomic status, and teacher training would be helpful to clarify these relationships and serve to better inform educators of best practices.

Limitations

My study included STEM courses only. It is in these academic areas that the United States lags behind other industrialized nations and so was of particular importance in my study. Since other academic areas were excluded from the meta-analysis it is unclear how a flipped pedagogical approach impacts achievement in these subject areas. The reasoning of why a flipped approach is effective indicates that engagement is a key component of an effective learning environment and flipping the class facilitates a student-centered approach. It is possible that flipping an English course, for example, might be significantly more effective than it is for a given STEM course.

In order to synthesize results about academic achievement in flipped classrooms, all studies in that particular domain should have been included in the meta-analysis.

However, the set of studies in this meta-analysis is incomplete due to unpublished research. There are likely educators that have experimented in flipping their classes that did not then author research papers for publication. Additional studies may have been conducted but were ultimately not included due to being published in databases that could not be accessed.

Implications for Social Change

As the world continues to become more technologically developed, the need for a skilled workforce in STEM fields becomes increasingly important. The innovations that are made possible through the contributions of science, technology, engineering, and mathematics bolster the economy, power, and leadership of the United States. If the U.S. is going to continue to compete in the global marketplace, the U.S. needs to be involved in continuing technological innovations. However, the U.S. falls short in STEM education, at all grade levels, compared to other developed and less developed nations. According to Kuenzi (2008), the U.S. ranks 20th in the world among college graduates that earn a degree in a STEM field. Investing money in elementary and secondary STEM programs is a good start. However, the lack of follow through that has been seen at the college level indicates that students are not interested in attaining a higher degree in a STEM field. At least, not at the rate needed for the U.S. to continue global leadership and innovation (Hossain & Robinson, 2012). It is more important than ever for educators to provide an engaging environment that fosters success and interest in these fields in order for students to have the confidence and motivation to pursue a higher degree in these fields.

The results of my study have implications for academic institutions that employ a STEM curriculum. Administrators and educators benefit from having access to research that will inform them of best educational practices. When teachers employ evidenced-based practices into their curriculum coupled with effective strategies, the school environment is elevated. Educators are less frustrated and better equipped to assess the learning outcomes that are embedded into the curriculum. In turn, the benefit to educators trickles down to the students. Students that are engaged are intrinsically motivated to succeed. The strategies used by teachers that foster engagement, self-efficacy, confidence, and improved ability may not be limited to a flipped pedagogy. Those strategies may be effectively woven into a traditional format and provide the same educational benefits.

There are larger societal benefits of this research as well. Improving a nation's education system, particularly for STEM areas, should be a goal of all that nation's citizens. Educated citizens become productive members of society that can promote the social and economic wellbeing of their communities. This is especially important as the world becomes increasingly reliant on technology and successful countries are seen as the innovators and problem solvers of the world. For the U.S. to continue to be competitive in the global marketplace, more U.S. students need to earn degrees in STEM fields. Success early on with STEM academic areas motivates students to seek a higher educational degree in that field rather than deciding to pursue a degree in the arts or humanities that, while certainly important, is not currently tied to our economic success in the same way.

Recommendations for Action

The Covid-19 global pandemic forced teachers to switch to online learning as the country's schools went into quarantine. Face-to-face time between students and teachers was drastically reduced as many teachers relied on video lessons and online worksheets to impart content knowledge to students. Teachers that had traditionally utilized a teacher-centered lecture approach, especially those without the necessary technological skills, assigned video lessons and readings followed by assessments. The computer became the lecturer but there was no face-to-face time. Learning became strictly a passive exercise for students, which decreased motivation, engagement, and academic success.

According to Mnguni (2019) the role of a teacher is to present content knowledge to students in an effective manner that students develop the skills needed for success in that subject area. According to this ideology, the traditional role of a teacher is to lecture and then assess student understanding. In this paradigm, the teacher is in complete control of content, active learning components, and assessments. When schools went online, teachers needed to adjust their teaching strategies, which included how they organized their classes. The traditional role of the teacher evolved to a less teacher-centered approach. Instead, the teacher is viewed as a knowledge facilitator and rather than controlling the environment, teachers monitor and guide students' use of technology. Teachers that shifted from a teacher-centered to a student-centered approach created online learning environments that were more effective compared to teachers that were unable to give up the lectures (Panisoara et al., 2020).

Student engagement leads to higher academic achievement because engaged students are more motivated. An engaged student is a student that is goal-directed, engages in flexible thinking, persistent, focused, and an active learner (Patel et al., 2019). Although educators have long assumed that a STEM based curriculum provides the necessary engagement through active learning such as problem-based-learning and inquiry tasks, this is not always the case nor is this hypothesis supported by current literature.

Academic achievement is improved through the implementation of a flipped classroom approach. However, how much improvement appears to be directly related to the quality, and engagement-potential of the lecture components of a flipped course. It is not enough for an instructor to simply refer a student to a YouTube video on a particular topic. Nor is it effective for an instructor to assign overly complicated or long duration videos and expect students to remain engaged. Microlectures can provide a means for educators to dip their toes into flipping their classrooms (Sweet, 2014). The microlecture is particularly attractive to teachers that may not be tech savvy or familiar with video-editing and content creation. This method of flipping is slow and allows educators to flip just one unit, or even lesson, at a time. Over time, more and more flipped content is integrated into a course curriculum without the loss of either lecture or active learning.

Recommended future research into the most effective teaching strategies for improving academic success and retention in STEM areas involves several key areas. Firstly, an examination of the benefits of technology and specific leaning strategies that rely on technology should be undertaken. Students that did not have access to reliable technology during the brunt of the Covid-19 quarantine were at a disadvantage so it would be advantageous to identify the key components of technologically infused lessons and activities that specifically improve student engagement, acquisition of knowledge, and understanding of concepts. Secondly, the implementation of the flipped approach varies considerably from study to study due to differences in educator ability and interpretation. The components of a flipped pedagogy that show the most promise in improving academic achievement should be identified. This leads to a follow-up research question as to whether these strategies can be equally applied in a traditional lecture approach. Essentially, it would be beneficial to know with some degree of certainty if the pedagogical approach or the teaching strategies employed are more effective at improving academic achievement. Finally, it would be worth examining if there are socio-economic or racial differences between groups of students that impact achievement in a flipped classroom.

Conclusion

Student engagement increases student academic achievement. Educators know that hands-on-learning experiences and peer interaction through collaborative group projects tend to increase student motivation and engagement. However, it is also too often the case that a classroom rich in hands-on-learning may be lacking in essential minds-on-learning that leads to engagement with the conceptual knowledge that students need to truly understand how and why a particular phenomenon occurs. A flipped approach can provide the link between providing quality lectures without compromising the active learning that occurs inside the walls of the classroom. The implementation of the flipped approach matters if it is to increase student engagement and therefore have a positive effect on student achievement. The literature supports that the most successful flipped classrooms utilize frequent formative assessments to ensure that students are adequately prepared for class. Then, those students are more motivated to persevere through difficult problem solving because they have the confidence and support to be successful. Perhaps academic success is predicted by assessment and engagement more so than teaching pedagogy. If that is the case, then flipping the classroom is not necessarily the most effective method of improving STEM education.

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Appendix A: Study-Level Coding Form

Bibliographic reference:
____

____________1. Study ID number [STUDYID]

____________2. Article included in analysis [INCLUDE]: 1. Yes 2. No
If No, Why
____

__________3. Type of publication [TYPEPUB]
1. Journal 2. Dissertation 3. Thesis 4. Conference Paper
5. Unpublished article

_________4. Publication year [PUBYEAR]

Study Descriptors

__________5. Grade level [GLEVEL]
1. Middle school (grades 6-8)
2. High school (grades 9-12)
3. Undergraduate
4. Unknown

__________6. Academic Course Type [ACADEMIC]
1. Chemistry
2. Physics
3. Biology
4. General science
5. Mathematics
6. Nursing
7. Engineering
8. Technology
9. Other STEM

_________7. Type of School [SCHOOL]
1. Private
2. Public
3. Not-specified

__________8. Predominant race [RACE]

1. >60 % White
2. >60 % Black
3. > 60% Hispanic
4. > 60% other minority
5. Mixed
6. Uncertain

___________9. Gender [GENDER]

1. <10% female
2. 11% -49% female
3. 50% female
4. 51%-95% female
5. >95% female
6. Information not provided

___________10. Geographic location [GEOLO]

Research Design Descriptors

___________11. Data source [DATAS]

___________12. Total sample size at start of study [TOTALN]

___________13. Total sample size at completion of study [TOTALEND]

___________14. Achievement outcome measured [ACHOUT]

1. Yes 2. No

___________15. Flipped pedagogy compared to Lecture pedagogy [FLPED]

1. Yes 2. No

EFFECT-LEVEL CODING

___________16. Study ID number [STUDYID]

___________17. Type of data effect size [TYPEES]

1. means and standard deviations
2. t-value or F-value
3. Chi-square
4. frequencies or proportions
5. correlation
6. other (specify)

___________Page number where the data for this effect was located [PAGEN]

_____________18. Flipped Outcome Mean [FLIPMEAN]

_____________19. Lecture Outcome Mean [LECMEAN]

_____________20. Flipped Standard Deviation [FLIPSD]

_____________21. Lecture Standard Deviation [LECSD]

_____________22. Significance Test: nondirectional t-value [TVALN]

_____________23. Significance Test: directional t-value [TVALD]

_____________24. Effect size [ES]

_____________25. Confidence rating in effect size computation [CRES]

1. Not estimated, reported in article
2. Estimated
3. Averaged

____________26. Effect size calculation type [ESCALC]

1. Means and standard deviation
2. t or 1df F statistic
3. correlation coefficient
4. proportions
5. p-value
6. effect reported, not calculated

_____________27. Source of means [SOMEAN]

1. Directly reported
2. Average of reported means
3. Obtained from graph
4. Means not reported, not used to calculate effect

_____________28. Source of standard deviations [SOSD]

1. Directly reported
2. Directly reported MSE
3. Calculated from means and s's
4. Calculated from a related t or d statistic
5. Calculated from a related F statistic
6. Calculated from a related p-value
7. SD not reported, not used to calculate effect