Clicking for the Success of all Students:

A Literature Review and Classroom Study

Investigating the Possible Differential Impact of Clickers

by

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A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved May 2020 by the
Graduate Supervisory Committee:

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ARIZONA STATE UNIVERSITY

August 2020

ABSTRACT

Clickers are a common part of many classrooms across universities. Despite the widespread use, education researchers disagree about how to best use these tools and about how they impact students. Prior work has shown possible differential impacts of clickers based on demographic indicators, such as age, gender, and ethnicity. To explore these topics a two-part project was designed. First, a literature review was completed focusing on past and current clicker practices and the research surrounding them. Second, original data, stratified by demographic characteristics, was collected on student perceptions of clickers. The literature review revealed that not all uses of clickers are created equal. Instructors in higher education first introduced clickers to enhance traditional pedagogies by simplifying common classroom tasks (e.g. grading, attendance, feedback collection). More recently, instructors pair clickers and novel pedagogies. A review of the identified benefits and drawbacks for students and instructors is provided for both approaches. Instructors can use different combinations of technological competency and pedagogical content knowledge that lead to four main outcomes. When instructors have both technological competency and pedagogical content knowledge, all the involved parties, students and instructors, benefit. When instructors have technological competency but lack pedagogical content knowledge, instructors are the main benefactors. When instructors have pedagogical content knowledge alone, students can benefit, but usefulness to the instructor decreases. When instructors have neither technological competency nor pedagogical content knowledge, no party benefits. Beyond these findings, recommendations are provided for future clicker research. Second, the review highlighted that clickers may have a differential impact on students of different demographic groups. To explore this dynamic, an original study on student views of clickers, which included demographic data, was conducted. The original study does not find significantly different enthusiasm for clickers by demographic group, unlike prior studies that explored some of these relationships. However, white students and male students are overrepresented in the group that does not enjoy clickers. This conclusion is supported by visual observations from the means of the demographic groups. Overall, based on the review of the literature and original research, if instructors pair clickers with validated pedagogies, and if researchers continue to study clicker classrooms, including which students like and benefit from clickers, clickers may continue to be a valuable educational technology.

DEDICATION

This paper is dedicated to my loving family for their continued support in my academic endeavors, trying to give me opportunities they did not have. They have worked hard since my birth, trying to give me a good life, in many ways at the expense of their health, well-being, and own dreams. I hope this achievement makes them proud and affirms that their many sacrifices and sleepless nights were not in vain.

To my wife, who has sacrificed so much for me to pursue my aspirations and dreams, who has been the best friend and rock I need. She has done more than I could ask or expect. She also brings joy into my life through others namely Perdita and Pumpkin. I hope to start paying her back, helping her to fulfill her dreams.

Finally, to the newest member joining our family, the hard work has been in large part for you. When times were rough, the thought of you made me work harder and longer than I could have otherwise.

ACKNOWLEDGMENTS

I would like to give special acknowledgment to my committee members who have been patient, helpful, and ever-present in helping me become a better academic and person. Without them, I could not have accomplished what I have.

My committee co-chair, Dr. Joesph Bryan Henderson, has pushed me to become a better writer, critical thinker, and academic. He has helped me to become more honest with myself and those around me, to not simply be a "yes-man" and to meaningfully apply myself to problems. He has also encouraged me to not take on too much or burn myself out. I thank him for his patience and persistence. I have become a better person because of his effort and feedback. Without him, this thesis would not have been possible. I also thank him for allowing our collaborative work to become Chapter 2 and for his support and guidance through its creation.

My second committee co-chair, Dr. Karin Ellison, has shown me how to keep myself sure-footed as I traverse bumpy or unpaved roads. She has been a large support in terms of helping me develop professionally and personally. Her weekly check-ins have kept me on track through this entire experience. She was always there to lift me up and push me to go further. Her consistent guidance helped me think about the world in new ways, always pushing to the "Why." She has been a constant voice and pair of helping hands at every point of this project, from inception to the final edits of this thesis paper. Suffice it to say, I could not have completed this thesis without her.

Dr. Matthew Chew has been a part of my education since I started this program. I have been his student, TA, and now colleague. He has been more than I ever could have asked for. He pushed me to rethink my thinking. He has shared many ups and downs throughout my academic career. He has helped me further define what kind of person I want to be.

I would also like to acknowledge the Biology and Society Center Director, Dr. Jane Maienschein for encouraging me at every step. Without her, I would not be in this program. I would also like to acknowledge her for always making me ask “So What?” I would like to acknowledge the staff and instructors of SOLS and the Biology and Society Program; they have made this experience enjoyable. They were always present to assist and solve whatever obstacles arose. I would also like to thank ILLIAD and the ASU Libraries; ASU did not have many of the works I used on hand and they were indispensable in retrieving material to assist my writing and research.

TABLE OF CONTENTS

CHAPTER Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

At a university, learning experiences can be vastly different from one course to the next. Moving from a local community college, with mostly small classes, to a large research university, I experienced these shocking differences. Walking into my first university class, I found myself surrounded by hundreds of other students. For the first time in my life, I would be taking a didactic, lecture-style, large-enrollment course. Over time, I experienced three general types of university classes: lecture, seminar, and flipped classroom. In lecture-based classes, professors mostly orate at length to the students. Lecture courses are a typical feature of many colleges, especially for large-enrollment courses. In contrast, during seminars students experience an intimate, small student to instructor ratio. Smaller numbers give instructors more freedom in selecting pedagogical approaches. Students and instructors can engage in deep discussion and other positive interactions. Students can focus, together, on learning. Students can also experience "flipped classrooms," which are in-between lectures and seminars in both student numbers and teaching approaches. An instructor leading a flipped course combines many different pedagogical ideas and engagement activities to give the students a well-rounded learning experience. Having experienced these different types of classes, many students can gauge how a class may unfold by simply walking into the classroom. I quickly concluded that in the classrooms seating 100 students or more, I should be prepared to take notes and nothing else. One class, however, led me to challenge this assumption and opened a window to many more options in teaching large-enrollment courses. On the first day of that class, my professor held up a clicker.

Clickers are an educational technology that allows students to respond to instructors during lecture. They can be used in many ways, but the most common use revolves around polling. Clickers take many forms including wireless devices, web-based programs, and even cell phone apps. In the literature, a common name for systems that allow for interactivity is Classroom Response System (CRS). CRS are not new technology (Judson & Sawada, 2006), but educational institutions are giving them increasing attention as a teaching tool. It is for this reason that I found purpose in trying to study and understand why clickers are a part of classroom life. At first, I was confused about why I needed a clicker in a lecture hall. I fear that too many students have similar feelings; they enter classrooms confused about why they are required to purchase and participate with clickers. It may seem just another menial classroom activity. This led me to ask the question, "What do clickers do for students?" To understand this question, background on clicker development and efforts to increase diversity in higher education generally, and science, technology, engineering, and math (STEM) fields particularly, will be helpful.

A Brief History of Clicker Development[1]

When looking at the history and current place of CRS, it is important to note the wide variety of names and forms of these devices. Commonly known as clickers, CRS, are an educational technology for eliciting student responses, anonymous or identified, that can be tabulated, displayed, and recorded in real-time. The manufacturing and distribution of clickers have become a multi-million-dollar industry with a growing

[1] With committee approval, this master's thesis includes material also submitted for publication as Chambers & Henderson, 2020. The article material appears in this section, the next, and Chapter 2 "A Review of Current Clicker Research…."

presence in science classrooms (Berkey, 2018; *Technologies*, 2019). Two decades have passed since the National Resource Council's *How People Learn* (Bransford et al., 2000) identified clickers as a promising new trend in education, and, with clickers more affordable than ever before, millions of students have now been exposed to the technology. Clickers offer a simple way for students to submit responses to questions posed by their instructor. In turn, the instructor uses a receiver that instantly captures student responses, and clicker software allows for real-time recording and display of this response data.

Names for clickers include student response systems (Penuel, Boscardin, Masyn, & Crawford, 2007; Trees & Jackson, 2007), audience response systems (Castillo-Manzano, Castro-Nuño, López-Valpuesta, Sanz-Díaz, & Yñiguez, 2016), personal response systems (Morling, McAuliffe, Cohen, & DiLorenzo, 2008), electronic response systems (Freeman, Bell, Comerton-Forde, Pickering, & Blayney, 2007; Judson & Sawada, 2002), electronic voting systems (Draper & Brown, 2004; Kennedy & Cutts, 2005), and perhaps most commonly, clickers (Caldwell, 2007; Hatch, Jensen, & Moore, 2005). Kay and LeSage (2009) found 26 different names for these similar classroom response technologies. Hereinafter, I use the term clickers to refer to these systems generally. While many of the studies do not include or took place before the advent of cloud-based CRS, which allow students to participate via web-enabled devices, many of the findings I present also can be applied to these clickers.

The concept of having an electronic way for students to respond to instructors can be traced to the 1950s when the United States Air Force used a rudimentary CRS to engage flight school students and poll for understanding (Froehlich, 1963). The introduction of clickers into higher education began when Stanford University secured funding to build the Stanford Center for Research, Development, and Teaching in the 1960s. This building was equipped with the latest technologies: a television studio, videotape recorders, TV monitors, giant pull-down projection screens, projectors, technician stations, and a clicker at every desk (*History*, 2018). While many of the technologies aimed to aid the instructor in presenting material, clickers offered a novel method for students to respond during class, receive feedback, and gauge their understanding. Clickers also provided the instructor with an insight into the students' grasp of a subject (Judson & Sawada, 2006). At their inception, clickers were designed to replace other modes of student response e.g. polling, raising hands, cold calling. Using clickers was an innovation in classroom dynamics. Despite the period and purpose of these clickers, the systems were not simplistic. Many systems were complex in what they could accomplish, having lights to indicate when a student was right or wrong, lightboards that allowed professors to view quickly how the class responded, multiple-choice response capability, some with dials allowing for combinations of answers, and built-in timers (Abrahamson, 2006; Dworetzky, 1976; Judson & Sawada, 2006). The classroom was becoming more interactive, rather than a traditional lecture format, where instructors only present to students during the class period. As the use of clickers began to spread, scholars began studying the effects. Early work showed that there were no additional learning gains when compared to a normal lecture classrooms (Bapst, 1971; Bessler, 1969; Bessler & Nisbet, 1971; Brown, 1972; Casanova, 1971; Chu, 1972). However, researchers wrote that students had a positive perception of clickers and their use in the classroom (Bapst, 1971; Brown, 1972; Casanova, 1971; Chu, 1972; Garg, 1975). Students were noted as being more engaged in class since clickers allowed participation even in large group settings.

John Seely Brown (1972) examined the effects that clickers had on student learning, finding that while clickers may not affect learning gains, they proved valuable in enhancing student engagement and experience. Comparing classes that used clickers and traditional classes, Brown drew four main conclusions. First, all students had comparable learning gains, irrespective of whether they used clickers or not. Second, students who used clickers experienced less anxiety during lectures. Third, students had better attitudes toward the class when using clickers. Finally, although the contribution of better attitudes and decreased anxiety did not significantly increase the achievement of the treatment group, these benefits alone warranted continued use of clickers (1972, pp. 18–19).

Yu-Kuang Chu (1972) in a report to the National Science Foundation, noted how clickers gave the instructors the ability to generate discussion among students. It gave a chance for the students to meet new people and collectively discuss their ideas. He also noted the use for collecting information on student opinion, deducing comfort level with the material, and monitoring students' study. With positive findings, more institutions bought and incorporated these devices into classrooms and learning environments (Abrahamson, 2006).

With researchers' findings supporting clickers, surprisingly, the research being performed after this initial implementation declined sharply. Judson and Sawada (2006) attribute this "cool-down" to universities losing interest in clicker technology. Louis Abrahamson (2006) recounts his experience in designing one clicker system and the struggles related to early clickers. His account supports the conclusion that although those early clickers did have promise, they were prohibitive in cost, required too much maintenance, were limited in capability. To illustrate this, an early user said "[clickers] never worked and [were] a total pain to use" (as cited in Abrahamson, 2006, p. 3). Despite these issues and the temporary decline of publishing on the topic of clickers, studies continue to show that there is benefit in using clickers (Draper & Brown, 2004). With persistent promise, developers continued to work on clicker systems. Modern technology has helped to make clickers more cost-effective and accessible to students. Technology has also expanded what clickers can be used for. Due to these advances, a renewing of excitement took place in the 1990s (Abrahamson, 2006). As instructors have once again begun to introduce clickers into classrooms, the benefits first observed in the 1970s are again observed by researchers, instructors, and students today (Kay & LeSage, 2009).

As instructors, researchers, institutions, and students have recognized clickers for their positive contributions to the classroom, the market has increased for the manufacture and sale of clicker systems. Notable manufacturers include Dell, Macmillan Learning, iClicker, Turning Technologies, Smart Technologies, and others. The market has steadily increased since the early 2000s and is continuing in a similar trend (T. Gordon, personal communication, March 28, 2019). Projections show the industry increasing at a CAGR (Compounded Annual Growth Rate) of 30.07% from 2016-2020 (TechNavio, 2016). Turning Technologies was named the "fasting growing privately held software company in North America" in 2007 from *Inc. Magazine*, the 18th fastest-growing privately held company from the same magazine and 3rd in the 2018

Entrepreneur Magazine fastest-growing small businesses (T. Gordon, personal communication, March 28, 2019). With the growth in the industry and an increase in clicker implementation into classes, research has continued to explore the influence clickers have on students, instructors, and the classroom.

Similar Technology Does Not Mean Similar Pedagogy[2]

An important feature of clickers is the instant feedback that provides a real-time gauge of student understanding (Caldwell, 2007; Crouch & Mazur, 2001; Draper & Brown, 2004; Kennedy, Cutts, & Draper, 2006). Clickers make both teachers and students privy to immediate feedback, which can be used for formative assessment (Black & William, 1998; Sadler, 1989). By showing teachers what students are confident with and on what topics they need further assistance, instructors can adjust their presentation of content. Yeh (2009) argued that the implementation of formative assessment systems to track student math and reading performance two to five times per week were found to be 124 times more cost-effective than class size reduction in improving student learning.

Different instructors use feedback generated by clickers in different ways. When the first uses of clickers were documented in the 1960s, behaviorist stimulus-response principles were at their peak and, hence, clickers were used primarily to provide immediate response feedback on student performance (Judson & Sawada, 2002). More than half a century later, there are a growing number of constructivism-influenced uses of

[2] This modified section is from a manuscript submitted for publication (Chambers & Henderson, 2020).

clicker feedback, the most common of which is the use of clickers to promote student discussion with both their instructors and their peers (Judson & Sawada, 2002).

The difference in clicker pedagogy is not just a historical one. In today's clicker classrooms instructors pose clicker questions in a variety of ways; the degree to which they interact with students during peer discussion sessions differs, and they maintain different norms for discussion (Turpen & Finkelstein, 2007). Along with changes in technology and pedagogy, it is important to note the progress in education that was happening at the time. Specifically, in this period of the 1950s to the present, vast improvements to education equality were taking place.

Striving for Equality in Education and Science Education

While clickers were being popularized as a new teaching tool, there were great societal changes taking place. The 1960s saw the development of society at large. In the United States specifically, many different movements were taking place among these: The Civil Rights Movement, The Disability Rights Movement, and The Anti-War movements (Coleman & Ganong, 2014). While these are some of the most famous, another rallying cry of the 1960s and 1970s was for education reform (Southerland & Gess-Newsome, 1999). While many of these movements focused on equality across society, the education movement sought to bring equality specifically into the classroom. In notable instances, these movements overlapped. Although desegregating schools began with the Little Rock Nine in 1957, desegregation was still being fought for through the 1960s. There was a common purpose in trying to make quality education accessible for all people, not just a select few. This period also brought more federal oversight into education. Before the 1960s, education was left to the individual state's jurisdiction. With the passing of the Elementary and Secondary Education Act in 1965, the government began to play a bigger role in the local schools. In part, this included approximately $1 billion that was set aside to help the nation's poorest schools (Cordasco, 1976). Society became more mindful of the different groups in society, especially those that had been previously excluded whether physically, financially, or otherwise. The idea that diversity is a good thing became popularized. The benefits of diversity in education and sciences have been shown by the increased innovation by different people from different ethnic groups. The understanding that differences are good in education has become the

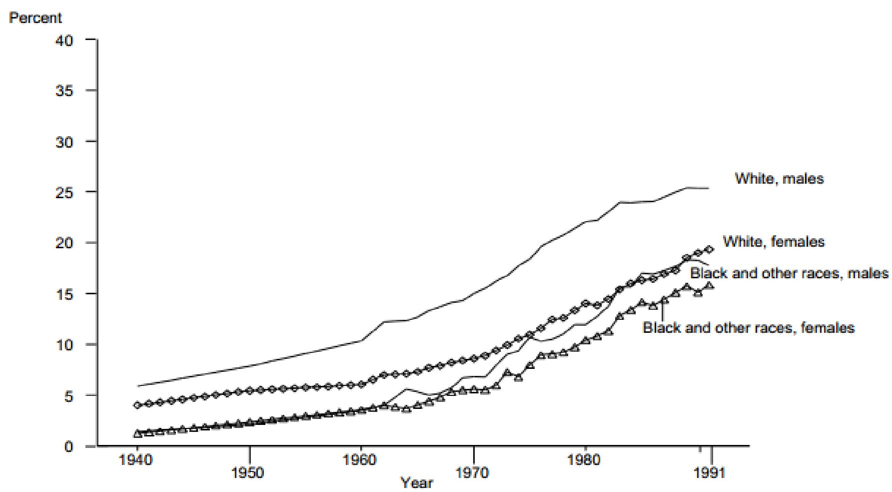

Figure 1. A graphical representation of the percent of persons 25 years old and over completing 4 years of college, by sex and race from the years 1940 to 1991. Source: 120 Years of American Education: A Statistical Portrait, 1993, p. 8

accepted narrative in modern-day education (Gurin et al., 2004). Today, students in higher education are more diverse and many of the inequalities of the past have been defeated or overcome. Due to societal changes, educational paradigm shifts, and efforts to make education more accessible, increased academic attainment by all demographics can be seen from the 1940s to the 1990s. In a review of education in North America, the US Department of Education commissioned the statistical analysis of data, provided by the US Census Bureau. Figure 1 provides a graphical representation of the attainment of four-year degrees by demographic groups from 1940 to 1991. This graph shows positive changes in accessibility and equality in education (120 Years of American Education: A Statistical Portrait, 1993). ASU's charter summarizes nicely, "ASU is a comprehensive public research university, measured not by whom it excludes, but by whom it includes and how they succeed; advancing research and discovery of public value; and assuming fundamental responsibility for the economic, social, cultural and overall health of the communities it serves ("ASU charter," 2019)." Despite these gains, there is still inequality in education and science education. No longer is the inequality caused by who is excluded, although this has recently become a renewed topic of discussion (Anderson, 2018), but rather by what happens once they are admitted. While not exclusive to any specific major, there has been a lot of work illustrating this dynamic in STEM fields (Cordasco, 1976; Friedman, 2004).

While more students were seen enrolling and receiving degrees, contrary to expected results, college STEM majors did not follow these trends. While enrollment increased, attrition rates were higher than non-science degrees (Seymour & Hewitt, 1997). Conceptually, more students should have had access to the tools needed to perform well in these disciplines, yet there was still some sort of disparity occurring. In 1990, the UCLA Higher Education Research Institute (H.E.R.I.) published findings that showed a decline in students, specifically undergraduates, choosing to enter or remain in a course of scientific or mathematics-based study during their time in the higher education system (Seymour & Hewitt, 1997). Spurred by the increase in those who left STEM fields during the study and a decrease in enrollment to these programs, Seymour and Hewitt poised the question, “Why do students leave?” Their findings suggest trends in which students leave, separated by different demographics, and the reasons they choose to leave. The study showed that 44.1% of students who begin their study in a STEM field will leave that field; this contrasts with other disciplines, Humanities/Social Sciences seeing 29.9% switch majors. Their work provides attrition rates by sex. From the STEM majors only ~23% of females stayed in the same major that they began their studies in. In the sciences, males were much more likely to remain the field in which they began their studies. This is just one example of a continued disparity even after entrance barriers were removed.

The National Science Education Standards (NSES) include the following declaration, “All students, regardless of age, sex, cultural or ethnic background, disabilities, aspirations, of interest and motivation in science, should have the opportunity to attain high levels of scientific literacy” (National Science Education Standards, 1996, p. 2). The inclusion of the statement, “regardless of age, sex, cultural or ethnic background” highlights the grounds on which students may feel displaced in science (Committee on Underrepresented Groups the Expansion of the Science Engineering Workforce Pipeline, 2010). When looking to implement new technologies or methods in the classroom one must consider the differing needs of these groups and aim to be inclusive of them all. Today, improvements in the education system have resulted in the increased enrollment of females in STEM courses: for example, an average of 60% of enrollment in biology classes is female. However, participation and retention still are left wanting. Less than 40% of enrolled females participate in verbal responses (Eddy et al., 2014). The disparity does not persist based solely on sex. Underrepresented minorities, for example, while having increased enrollment are continually underrepresented in scientific fields, disproportionately drop-out, and lack in areas of participation and engagement in the classroom (Seymour & Hewitt, 1997). Students from a wide variety of backgrounds participate in STEM fields at lower rates due to conflicts, or perceived conflicts, between STEM and their worldviews (Barnes et al., 2017; Barnes & Brownell, 2017). These continued disparities are not lost on educators nor educational engineers. New systems and technologies are constantly being developed to foster an increase in student learning, participation, and retention. Clickers are one technology that is meant to accomplish this goal.

When looking at the journey of education from the 1950s to modern education, some key trends stick out and become very important when talking about clickers. Education, moreover, quality education, was inaccessible to a wide variety of people before the movements of the mid-20th century. Active efforts to include more people in education increased accessibility. While this is a great accomplishment, modern efforts to deeply explore student performance and interaction have shown that there are still inequalities between students of different demographics. Considering these persisting differences, it is not trivial how classroom instruction should occur. Clickers have become a large part of many classrooms, as such, research is needed to fully appreciate how they affect the learners that use them.

Approaching the Question: A Project Overview

Since the use of clickers in classrooms has grown substantially and the literature about clickers has increased along with it, there is an opportunity to explore the benefits and drawbacks of using clickers by reviewing the large literature about them. During the review, I was able to focus on more specific questions, which include: What are the current uses of clickers and what impact do they have on students? What are the best practices in clicker use and how should they be implemented? I was able to identify some general trends in the research that has been conducted. Much of the work that I reviewed was performed in STEM classrooms, mainly within higher education institutions. Many of the studies I looked at focused on perception. When looking at different papers that explored learning gains, I found disagreement as to whether clickers improved learning or not. A final trend is that, within perception studies, a consistent percentage of students respond that they do not like using clickers (Caldwell, 2007). Considering current and past inequality within education, especially science education, I was interested in who comprises this group. This gap in such knowledge led me to conduct original research aimed to answer the question of who this group might be comprised of, or more specifically, to look for differential impact of clickers by group. My driving question was: Provided that science classrooms include a diverse set of students (e.g. students from different races, ethnicities, genders, worldviews, etc.), how do clickers encourage participation by these different groups?

So, my research became two-part: the first part tries to understand generally the impacts of clickers on students and the second focuses on how students from different demographic groups are impacted by clickers, especially the students who respond negatively to clickers. First, I conducted a literature review to identify the effects that clickers have on students generally. Second, I undertook an original study to look at the possible differential impact of clickers and the composition of the group of students that respond negatively to clickers.

In the literature review, I identify common uses of clickers and the effects of these uses on students and their instructors. Historically, clickers were used as a direct substitute for hand-raising, but now instructors use clickers to promote interaction and discussion in the classroom setting (Kay & LeSage, 2009). Current practices of clicker use can be divided into two categories: 1) instructors using clickers to enhance traditional classrooms, or 2) instructors using clickers with modern and novel pedagogies.

In enhanced traditional classrooms, clickers are added to a class, without novel pedagogy. Clickers have instrumental value when used in this fashion (grading, collecting and distributing assessment material, attendance, etc.); they can ease instructor burdens (Aljaloud et al., 2015; Draper & Brown, 2004; El-Rady, 2006; Freeman et al., 2006; Freeman & Blayney, 2005; Guse & Zobitz, 2011; Kay & LeSage, 2009; Kay & Knaack, 2009; Preszler et al., 2007; Walklet et al., 2016). In classrooms where clickers are paired with novel pedagogy, there is not only instrumental value, but also an increase in student learning (Barrio et al., 2016; Beatty et al., 2006; Bruff, 2009; M. M. Cooper, 1995; Crossgrove & Curran, 2008; Crouch & Mazur, 2001; Goodwin & Hoffman, 2006; Lasry et al., 2008). Many of the novel pedagogies use clickers to facilitate discussion (Lasry et al., 2008; Beatty et al., 2006; Crossgrove & Curran, 2008).

Students and instructors struggle with clickers in both categories of use. In enhanced classrooms, instructors have concerns about technology, clicker questions, content, and time usage. Students struggle with concerns about technology, common classroom practices, financial burden, and participation. In modern pedagogy, similar concerns about technology are present but instructors face more questions about content. Students must also deal with new aspects of classroom interaction. The culmination of the literature review presented in Chapter 2 is illustrated in Figure 2, which highlights the outcomes of the different clicker classrooms. Overall, clicker research needs to shift away from general student perception and towards nuanced understanding the effects of clickers. Fostering inclusive classrooms demands a better understanding of this impact. I conclude the literature review by discussing recommendations for clicker use and research on clickers.

Spurred on by the limited work surrounding the idea of differential impact related to clickers, the original research was conducted to explore the question: Provided that science classrooms include a diverse set of students (e.g. students from different ethnicities, genders, and worldviews), how do clickers encourage participation by these different groups? The research consisted of an exploratory study to determine student perception of clickers grouped by demographic information and the composition of the group of students who respond that they do not like clickers. The statistical analysis yielded no significant results. By examining means visually, however, it was observed that white students had overall lower means on the instrument items when compared to the other race/ethnicity groups and that males had lower means when compared to females. The exploration of the specific group of students yielded similar results about the ratio of students from different demographics who respond negatively to clickers. The overall percent of males in the group was twice that of females. White students also had the highest percentage in this group. The complete results from the study are included, along with the next steps for future work, with improved methodology. A second study was planned, but, due to the global events of the global pandemic COVID-19, it was not completed.

An initial response to this line of inquiry might be, why does it matter how instructors use clickers or how students might respond differently? Why does it matter how education unfolds in a classroom, lecture hall, or any other place of learning? Simply, “[e]ducation has no higher purpose than preparing people to lead personally fulfilling and responsible lives…. The world has changed in such a way that science literacy has become necessary for everyone, not just a privileged few: science education will have to change to make that possible” (Rutherford & Ahlgren, 1990, p. xvi). Why science education specifically? Science education is a crucial part of the modern human experience. Science, more so now than ever before, exists in every aspect of our lives. For this reason, discussion of how scientific teaching and learning should occur in classrooms (i.e. what should it look, sound, and feel like) is not trivial. With advancing technology and knowledge, the idea of what a classroom should look like has drastically shifted over a relatively short period. With so many advances in technology, there is a veritable arms race between novel pedagogies and emerging technologies. As technology becomes available, researchers, companies, and instructors try to implement it into classroom life for a variety of purposes: increasing efficiency, increasing enjoyment, or hoping to increase student learning. But, what are the impacts on all students?

CHAPTER 2

A REVIEW OF CURRENT CLICKER RESEARCH AND RECOMMENDATIONS FOR THE FUTURE

The Present: Two Prevalent Trends in Clicker Use[3]

There is a wealth of literature about clickers and their effects on college students. There are two classroom settings where clickers are used by instructors: enhanced traditional classrooms and classrooms that pair clickers with more novel pedagogies. By looking at these classrooms separately, I was able to see benefits and drawbacks based on the unique use of clickers in each setting. First, I will report on my findings about the "enhanced classroom" followed by a discussion about clickers and novel pedagogies. Each of these sections is broken into two subsections, one looking at the benefits and one looking at the drawbacks. I further separate these by student and teacher perspectives. I provide some suggestions to help alleviate some common concerns about clickers. After discussing these trends and giving suggestions, I highlight the research being done on clickers, noting areas that could be further developed and explored. I end with a discussion about the four outcomes I identified when combining clickers with the two classroom types. These different pairings yield different outcomes for learners and instructors. To this end, I conclude that a guiding principle when deciding if and how to use clickers is incumbent on the professor and the desires they have for their students. Clickers benefit students more when paired with novel pedagogy than in a classroom with only new technology.

[3] This is chapter is a modified section from a manuscript submitted for publication (Chambers & Henderson, 2020)

My search through the literature began with a few key sources and was broadened into a systematic search. I started with two books and one paper from my Co-Chair: Eric Mazur's *Peer Instruction* (1997), Kay and LeSage's review of clicker literature (2009), and David Banks' *Audience Responses Systems in Higher Education: Applications and Cases* (2006). By reading these first, I was able to follow their bibliographies to more work that discussed the topics I was interested in. To expand the search, I used The Wiley Online Library, ASU Library's OneSearch, EBSCO Online Library, and Google Scholar. The search terms I used were "clickers," "classroom response system," "audience response system," "electronic response systems," "student response system," "CRS," "ARS," "SRS," "ERS," "clickers active learning," "clicker pedagogy," "classroom response system pedagogy," "clicker best practices," "clickers learning gains," "clicker history," and "clickers engagement." As I read, search terms changed to address new findings by pairing phrases like "race," "ethnicity," "gender," "equity," "culture," "differential impact," "inequality," and "negative impacts" with the different designations of clickers.

Trend 1: Clickers in "Enhanced Traditional Classrooms"

Potential affordances in enhanced traditional classrooms. After 50 plus years, instructors still choose to use clickers in traditional lecture-style classrooms. These classrooms become "clicker-enhanced classrooms" and are reminiscent of the first classrooms where clickers were implemented. The original benefits, identified by early researchers, persist. With technological advances, companies, researchers, and instructors have developed more uses for clickers to save time and effort. These methods include test administration, attendance, quizzing, grading, reading checks, and participation tracking.

These practices benefit instructors by decreasing the time spent on assignment collection and grading, increasing efficiency in classroom practices, and decreasing paper usage (Draper & Brown, 2004; Judson & Sawada, 2006; Kay & Knaack, 2009; Nielsen et al., 2013; Robertson, 2000).

Student perception. When instructors implement clickers in traditional classrooms, benefits can be identified and measured. Kay and LeSage (2009) examined 67 peer-reviewed articles and book chapters surrounding clickers, 64 of which were published after 2000. Thirty-eight of these articles examined attitudes towards clickers, and 36 of those articles reported generally positive attitudes towards clickers by students and/or teachers.

Attendance and participation. Attendance increases as clickers help students to become an essential part of the classroom environment (El-Rady, 2006). By assigning points to attendance activities, students are encouraged to come to class: being rewarded for coming or punished for not. Clickers have also proven useful in working with large class sizes, common in larger universities, by allowing more students to be a part of classroom activity (El-Rady, 2006). With more chances to participate and interact in class, students tend to have increased attention during lectures (Draper & Brown, 2004; Kay & Knaack, 2009; Preszler et al., 2007; Walklet et al., 2016). Clickers aid in creating *interactivity* or *active learning* (Siau, Sheng, Fui-Hoon Nah, 2006). This dynamic is a highly discussed benefit of clickers as they enable students to become contributors to classroom interaction, rather than idle observers. Clickers assist in creating this environment by allowing instructors to ask thought-provoking questions and allowing them to view student responses instantly (Caldwell, 2007; Crouch & Mazur, 2001;

Draper & Brown, 2004; El-Rady, 2006; Freeman & Blayney, 2005; Guse & Zobitz, 2011; Kay & Knaack, 2009; Preszler et al., 2007; Walklet et al., 2016).

Anonymity. Anonymity is one benefit of clickers that is provided irrespective of class size. In a class without clickers students respond to polling or questions posed by the instructor through hand-raising, cold-calling, or facilitated student selection (name jar, seat number, etc.). In all these instances students may experience social pressure. By using clickers, students can contribute without the worry of social pressure (Freeman, Blayney, & Ginns, 2006). Like social pressure, *stereotype threat* is another pressure that students may face in the classroom. Stereotype threat is the risk of confirming a negative stereotype about a group the person belongs to (Spencer et al., 2016). This negatively affects students who belong to groups that are stereotyped to have lower performance, less proficiency, or lower ability. When faced with a task, with performance stereotypes, students may perform below what they are capable of due to the pressure of the stereotype (Forbes, 2009). Commonly identified groups include minorities and females (Aronson, Quinn, & Spencer, 1998). Clickers provide anonymity that allows students to escape stereotype threat, helping to alleviate anxiety (Forbes, 2009). This effect is observed as students tend to prefer clickers over the traditional methods of classroom response (Freeman et al., 2007, 2006; Kay & LeSage, 2009).

Testing. Clickers can be particularly useful in testing. Clickers as a testing tool, eliminate the need for using scantrons and other paper instruments. This change helps move toward more efficient testing practices and reduces the time needed to distribute materials. Clickers can provide an instant grade and instant feedback on performance to students too. Instant feedback allows students to better prepare for future exams, as they know instantly what areas they should focus on during future studies (Bruff, 2010).

Present concerns in enhanced traditional classrooms. Despite all the benefits to instructors from enhancing a traditional classroom with clickers, instructors and students face issues in these classrooms. Instructors struggle with setting up the technology, using technology during class, and developing activities. Students face technological challenges too, and have concerns related to certain instructor practices. While some practices have benefits for instructors, not all these practices benefit students. Researchers must evaluate these practices and find the best way to aid instructors while minimizing harm to students.

***Instructors*.**

Training. When introducing clickers into any classroom, the instructor will have to become accustomed to the new technology, as such instructor training and capability to use clickers are a major concern (Nielsen, Hansen, & Stav, 2013). Instructor deficiency with technology and lack of training hinder the ability of an instructor to use clickers effectively in the classroom (El-Rady, 2006; Siau, Sheng, Fui-Hoon Nah, 2006; Sharma et al, 2005). Lack of technical knowledge leads to wasting time and energy, while not reaping the benefits of clickers (Lantz, 2010).

Content and question balance. A common concern for instructors is that less content is delivered when clickers are utilized in a classroom (Burnstein & Lederman, 2001; Caldwell, 2007; Dijk, Berg, & Keulen, 2001; Draper & Brown, 2004; Freeman et al., 2007; Sharma et al, 2005). This is a challenge related to implementing clickers, especially when instructors may not be able to reduce the amount of material covered by the course (Fagen et al., 2002). While students are provided only one to two minutes for a response, if ten questions are asked in a 50-minute class period, a fifth of the class is dedicated to clicker activities.

Preparation time. The process of developing questions for clicker activities has been called time-consuming and laborious by instructors (Fagen, Crouch, & Mazur, 2002; Paschal, 2002; Robertson, 2000; Horowitz, 2006 Aljaloud et al., 2015). While creating questions may seem like a menial task, questions are a key ingredient for effective clicker implementation. Even if the questions are used to simply engage students and collect participation points, poor questions will yield poor results (Nielsen, Hansen & Stav, 2013). This places an added burden on teachers, requiring more time to prepare for class.

Students.

Technology. A key student concern with clickers is facility with the technology. A study discussing student concerns found, "Students mentioned technical problems (25%), poor use of the technology (15%), and wasted class time in fixing problems (12%)" (as cited in Lantz, 2010, p. 557). Among those who responded positively, it was still reported that 47.8% struggled with the technology. These concerns echo the concerns raised by teachers who worked with early clickers (Abrahamson, 2006). Just as instructors must become familiar with clickers, it takes time for students to become familiar with clickers (Fagen et al., 2002; Siau et al., 2006). Even after students become accustomed to clickers, about 30% still do not approve of using them (Caldwell, 2007). There is little work that discusses the breakdown of the 30% of students who disapprove of clicker use.

Testing. The ease of collecting student responses may be a prime reason for clickers being used for summative testing but, students have reported using clickers for testing is not a preferred use (Caldwell, 2007; Kay & Knaack, 2009). Despite the potential advantages, if students dislike clickers being used as a testing tool, it may negatively impact their perceptions of clickers. For example, some students experience test anxiety. If students have test anxiety, they are prone to experience lower levels of achievement, decreased social functioning, and lower self-worth (Jones et al., 2000). Associations are a factor in test anxiety (Sapp, 2013). When clickers are used for testing purposes, students will begin to associate clickers with testing, possibly leading to a negative perception of clickers. This is exacerbated when a large percentage of the class grade is based on clicker participation (Caldwell, 2007).

Attendance. Similarly, students do not like being forced to attend class through clicker participation points or monitoring attendance via clickers (Caldwell, 2007). Since students dislike using clickers for attendance, they find ways to undermine the data produced by clickers. For example, students have found ways to misrepresent their class attendance and participation. Popular media threads showcase multiple students openly admitting that they use other peoples' clickers (Basquiat, 2018). Clicker abuse has even made headlines. At Dartmouth College, instructors caught students using other absent students' clickers to make it appear as though they were attending, falsifying the attendance reports generated by clickers. Clicker points represented 15% of the students' final grades, so students would use other students' clickers to help them receive those points, albeit dishonestly. Out of 272 students in the class, 64 (24%) were accused of cheating by this method (Jacobs, 2015). The negative perception of clickers when used for attendance is particularly concerning as preliminary research shows that negative views may generalize to other uses of clickers (Caldwell, 2007).

Financial burden. With more college costs shifting to students, higher education costs, and debt on the rise, required course purchases can burden students (Johnstone, 2004; Johnstone & Marcucci, 2008; Leslie & Brinkman, 1987; Metcalf, 2005). Textbooks already cost students around $1200 a year (Martin et al., 2017). Modest clicker costs add to an already large expense. While clickers can add value to the classroom experience for students and instructors, instructors, and institutions should consider the burden on students. Universities can distribute the costs of setting up clickers in multiple ways. For example, some companies roll the expenses for set-up, maintenance, or upgrading of classroom components into the cost of individual clicker cost and student subscriptions. Institutions and students could split these charges, but in many higher education institutions, the student pays them (T. Gordon, personal communication, March 28, 2019). A common device can cost upwards of $30, while a subscription can cost $25 a year (*Pricing*, 2020). Based on these costs, at $55 a student, the start-up cost for a 30-student class would be $1650. These calculations are based on a single class using the system for the first time. If students use clickers in multiple classes, the cost per student, per instructional hour decreases. Still, costs may prohibit some students and institutions from purchasing clickers.

Decreased participation. Carla Carnaghan and Alan Webb (2007) found that students were less likely to ask or answer questions aloud during classes using clickers. They compared two groups of students by the number of verbal questions asked and verbal answers given before and after clicker introduction. One group began with clickers and the other without and after five weeks they switched. The number of student verbal questions and answers given during these two periods were collected and then compared. When averaging individual responses in a class session, both groups of students asked and answered fewer questions during clicker use. This finding that students answer fewer verbal questions seems to be at odds with clickers being a means to increase interaction albeit facilitated through technology. Clickers do enable students to respond anonymously and in mass, but is that the only kind of response that matters? The second finding is thought-provoking as it investigates the other side of classroom interaction, that students are less apt to ask questions during class. This decrease may stem from students being accustomed to or preferring the anonymity that clickers provide, and not wanting to leave that safety. The authors regard their research as preliminary, advocating the further study of this topic. Some clickers and clicker programs include the option for students to ask questions with them, maintaining some level of anonymity.

Trend 2: Clickers in Novel Pedagogies

Potential affordances in novel pedagogies. Kay and LeSage (2009) discussed the possible benefits of using clickers in the classroom subdivided into two general areas: learning benefits and assessment benefits. Among the learning benefits, students interact more with each other, improve their reasoning abilities, and increase their conceptual understanding of the topics. Among the assessment benefits, formative assessment allows instruction to be modified based on student feedback, students receive more frequent feedback on their performance, and students can more readily compare their performance to the performance of others. While simply using clickers to enhance a traditional classroom has logistical benefits, some question whether students have more learning benefits or higher learning gains in these classrooms. Some studies indicate an improvement in student academic performance during summative assessments, while others challenge these findings in arguing that clickers do not improve scores (Anthis, 2011; Karaman, 2011; Kay & Knaack, 2009; Kenwright, 2009; Mankowski, 2011). By themselves, clickers may not be enough to improve learning gains, even if they facilitate the logistics of teaching (Byrd, Coleman, & Werneth, 2004; Lasry, 2008). Pairing clickers with novel pedagogies, especially those that incorporate student discussion, can increase learning gains, and positively affect student perception

***Novel pedagogies*.**

Cooperative Learning. I chose to focus on four pedagogies that use clickers in novel ways. The first of these is "Cooperative Learning." Cooperative learning is predicated on the idea that learning is a group effort and that working together with other students can improve learning and the learning environment (Cooper, 1995; Jensen, Moore, & Hatch, 2002). Students engage in group activities where they must complete structured tasks and assignments. This pedagogy has shown benefits to students: retention, engagement, higher-level thinking, and increased grades (Cooper, 1995; Cortright, Collins, Rodenbaugh, & DiCarlo, 2003; Jensen et al., 2002). One example of cooperative learning is cooperative quizzing. A common method of cooperative quizzing has students do both individual tests and group tests. For group tests, the instructor splits students into small groups and encourages them to discuss and compare answers during the test. They are especially encouraged to examine why some answers are right and others are wrong. Although this may be foreign to instructors and students alike (Nonacs, 2013), students discussing and working together helps students to develop a better understanding of the topics. Zeilik & Morris (2004) found that students had a 10% overall increase in the class average score after implementing cooperative quizzing. They cite a study by Byrd et al. (2004) where an increase in the mean final exam scores went from 57% (2001, no cooperative quizzes) to 80% (2002, cooperative quizzes) and class GPA increases from 3.80 to 4.33 where an A=5 and an F=1. Pairing this pedagogy with clickers helps combine the benefits of clickers with the benefits of cooperative learning which improves the learning experience and leads to higher learning gains (Crossgrove & Curran, 2008; Kelly, 2009; Leal, 2015; Nonacs, 2013; Zeilik & Morris, 2004).

Peer Instruction. The second, a well-known pedagogy, "Peer Instruction" (PI) likewise improves student learning. Eric Mazur developed PI in the 1990s. The basis of this pedagogy is centered around a sequence that students participate in. The sequence begins with students receiving a question and being instructed to answer by themselves. Students are polled for their answers. Students are shown the results and, depending on the percentage of students answering correctly, the instructor again poses the question now allowing students to discuss the question with their peers. They are encouraged to discuss the correct answer but can also be encouraged to explain why the other choices are incorrect. After the discussion period, the instructor again polls the class and displays the new results (Mazur, 1997). Clickers complement PI, as they speed up polling and ease the burden of recording student responses. PI can improve student benefits and learning, sometimes dramatically (Crouch & Mazur, 2001; Fagen, Crouch, & Mazur, 2002; Lasry et al., 2008; Schell & Butler, 2018).

Question-Driven Instruction. Beyond PI is a new pedagogy that recognizes its efficacy but expands and can outperform it. Beatty et al. (2006) presents "Question-

Driven Instruction," which also relies heavily on discussion. Question-Driven Instruction operates on the premise that students receive exposure to material completely outside of class and the only purpose of the class is to follow the *question cycle.* Instructors present students with a problem or question at the beginning of class. The students break off into small groups and argue over their various opinions and knowledge, utilizing the information they gleaned from the out-of-class materials. The instructor polls the students and a histogram is displayed, without revealing the "right" responses. This is followed by a moderated class-wide discussion, in which students volunteer to explain their reasoning behind the differing responses. Depending on the outcome of this interaction, the instructor provides observations, feedback, a micro-lecture, or presents another question. A class can go through three or four question cycles in a 50-minute period (Beatty et al., 2006).

Gamification. The final pedagogy is "Gamification." Gamification is predicated on the idea that making learning an engaging and fun experience can increase student benefits and learning. Gamification provides students with an opportunity to compete, discuss, score points, and be challenged while learning objectives still dictate the goals of the class (Banfield & Wilkerson, 2014). Common in gamification are game-show style formats that include things like being first to answer, sounds, countdowns, scaling answers, point-based question selection, leaderboards, etc. (Banfield & Wilkerson, 2014; Pettit, McCoy, Kinney, & Schwartz, 2015; Sun & Hsieh, 2018). Students can play by themselves or be a part of a group. Groups add peer-to-peer interaction. Students say that they enjoy gamification in class and that it engages them (Pettit et al., 2015). Gamification has been shown to increase learning benefits, student motivation, participation, and attention (Banfield & Wilkerson, 2014; Barrio et al., 2016; Pettit et al., 2015; Sun & Hsieh, 2018). Gamification uses clickers because they fit the pedagogy so well. Companies that design clicker software have already included things like scoreboards, game-type question structure, recording answer selection, and countdowns. Discussion again is a prevalent part of this pedagogy, as it was with the other three. One could ask the questions, is discussion what connects pedagogies where clickers are successful?

Student discussion is a common thread in successful clicker classrooms. Judson and Sawada (2002), in a review of over three decades of clicker use, concluded that only when student discussion took place did clickers positively associate with student learning. In a review of 76 papers surrounding clicker use, MacArthur and Jones (2008) found student collaboration in all studies detecting statistically significant learning gains. What is it about these student discussions in clicker classrooms that manifest in learning gains?

Crouch and Mazur (2001) analyzed clicker votes for an entire semester of introductory college physics. In cases where students voted on the same clicker question both before and after peer discussion about that question, they found that students answering correctly before peer discussion tend to maintain their correct position while, "the vast majority of students who revise their answers during discussion change from an incorrect answer to a correct answer" (Crouch & Mazur, 2001, p. 972). Knight and Wood (2005) reported a similar result with the use of clickers in an upper-division course in developmental biology over two consecutive years. They found that "almost inevitably, when a second vote is taken after three to four minutes of discussion, more than 75% of the class chose the correct answer” (p. 303). For reference, this phenomenon will be defined as convergence.

Given convergence on the correct answer when student discussion takes place between clicker responses, why do many students that first answered incorrectly move to the correct response after discussion? Mazur (1997) describes the discussion between clicker votes as an opportunity for students who know the correct answer to convince those who do not. Furthermore, Mazur advises that, if the percentage of students voting correctly on a conceptual question is less than 50%, “there are too few students in the audience to convince others of the correct answer” (p. 12). Here, students who determine the correct answer impart their understanding on others. This “truth wins” perspective – which essentially characterizes the upper limit of group performance as set by the ablest members of the group (Schwartz, 1995) – is a possible explanation for convergence. Under this view, if students change to a correct answer after being convinced by a peer who answered correctly, they may adopt the position of their discussion partner with little thought. This dynamic could be particularly common if they perceive their peer discussion partner to be knowledgeable on the topic at hand. For simplicity, henceforth imitation will be used to refer to this possible scenario – students in peer discussion groups passively and superficially change their answer to that of a discussion partner they deem to be knowledgeable and trustworthy.

Smith et al. (2009) provide evidence that convergence in peer discussion groups was not the result of imitation. In an introductory genetics course where students voted with clickers, instructors asked students to vote independently on a conceptual question (Q1) and then discuss that question with peers before individually re-voting on the same question after discussion (Q1ad). Then, instructors presented students with a second question (Q2) testing the same concept as Q1, only with different surface features. Smith et al. call these pairs of problems purporting to test the same concept isomorphs. Smith et al. found that when students were first incorrect on Q1, but then changed to the correct vote on the same question after discussion (Q1ad), 77% of these students went on to answer the isomorph question (Q2) correctly.

As Q2 had different answer choices and students answered Q2 without peer discussion, this result is not consistent with imitation. More specifically, if students changing to a correct answer on Q1ad were merely memorizing the number or letter of the answer selection suggested by a peer, then the percentage of the time they also answer correctly on Q2 should be more comparable to random guessing (e.g., 25% if there are four answer choices). Answering Q2 at a rate of 77% after correcting from a wrong answer on Q1 to the right answer on Q1ad suggests something deeper is taking place during the discussion between Q1 and Q1ad. Furthermore, Smith et al. (2009) found that even when a student answered both Q1 and Q1ad incorrectly, 44% of the time they went on to answer Q2 correctly. This success rate is greater than would be expected from random guessing, which is particularly remarkable as the researchers deliberately withheld any feedback on classroom voting on Q1 and Q1ad.

In contrast to the “truth wins” view that students with right answers transmit the correct response to those originally answering incorrectly, Smith et al. (2009) suggest a learning benefit from the peer discussion sections, even if no members of the discussion originally know the correct answer. Supporting this idea was the fact that when 328 students participated in an end-of-year survey, nearly half of these students disagreed with the following statement: “When I discuss clicker questions with my neighbors, having someone in the group who knows the correct answer is necessary in order to make the discussion productive” (p. 124). This result is consistent with the Schwarz, Neuman, and Biezunger (2000) finding that groups are capable of producing correct answers even when all of the group members were initially incorrect. Hence, when it comes to student discussion being a common thread in clicker studies that demonstrate learning gains, it’s hard to say the result is due merely to truth winning over students that imitate, especially considering evidence from multiple studies that truth can emerge even if no discussion partner originally understood that truth.

Mankowski (2011) further supports discussion as the reason for the success of these novel pedagogies. Mankowski studied two classes, one using clickers to respond after peer discussion, and the other responding with whiteboards after discussion. In the report, both classes experienced learning gains, but there was no statistical difference between the two. He cites a study by Martyn (2007) to support this finding. Martyn (2007) conducted a study looking at the effects of discussion versus of clicker use, like the Mankowski (2011) study. The discussion group spoke together and raised hands to poll on answers. The clicker group followed guidelines derived from the work of Robertson and Duncan (as cited in Martyn, 2007). These guidelines included items such as encouraging and giving time for discussion. The findings show no significant difference between the classes. Collectively, the studies presented by Mankowski (2011) do not present findings contrary to prior work done on discussion and clickers, but rather support the idea that discussion is the reason for success. This conclusion that pedagogy is the main force driving student learning gains was also reached by other studies (Draper & Brown, 2004; Lasry, 2008; Terrion & Aceti, 2012).

Flow. Recent research has aimed to better understand how clickers have specific effects on classrooms and learning experiences. One method has been to examine clickers through the theory of *flow* (Buil, Catalán, & Martínez, 2019). Flow, first identified by Mihaly Csikszentmihalyi (1975), is a state of total involvement where the effects of friendship and relaxation, risk and chance, problem-solving, competition, and creative activity enhance the enjoyment of any given activity. This theory stipulates three conditions for flow to occur: A balance of skill and challenge, instant feedback, and clarity of goals (Buil, Catalán, & Martínez, 2019). When flow is achieved, students experience positive benefits (Hamari et al., 2016; Kiili, Lainema, de Freitas, & Arnab, 2014).

Buil, Catalán, and Martínez (2019) aimed to evaluate whether clickers fulfill these conditions and create an environment where flow can occur for students. They report data as relationships between the three conditions for flow (a balance of skill and challenge, instant feedback, and clarity of goals) and desirable outcomes which are listed as concentration, sense of control, autotelic experiences (experiences that are driven by the participants' curiosity and sense of purpose), perceived learning, and satisfaction. Clickers, by providing instant feedback, help students concentrate more and feel a greater sense of control. Furthermore, students in this study reported both satisfaction with clickers and the perception that clickers enhanced their learning. Discussing the three conditions for flow to occur, clickers were not related to goal clarity, but the study found that clickers can help satisfy the need for immediate feedback and the balance of skill and challenge. In turn, clickers aid in the achievement of the subsequent desired outcomes. Ultimately, the study found strong support that clickers can "promote flow experiences and enhance the learning experience [of students]" (Buil, Catalán, & Martínez, 2019, p. 436). In their study, peer discussion paired with clickers helps create a preferred learning environment.

Problems when pairing clicker with novel pedagogies.

***Instructors*.** In these pedagogies, questions are the focal point, driving discussion and disagreement. Instructors create questions to fulfill this requirement. If questions and their alternatives fail to challenge students and fail to engage students in a genuine discussion about argumentation, the purpose of the pedagogy is not met. Time distribution becomes even more crucial. Polling in the enhanced classroom takes one to two minutes per question but in the classroom, where novel pedagogy is incorporated, more time is required. Discussion time, new cycles of questions, and more set-up time for students is dedicated to clicker activities. This draws even more time away from introducing new content.

Instructors may also struggle with how to best use clickers for learning. Kay and Lesage (2009) mention that teachers, due to inexperience, may struggle with fully utilizing the student feedback provided by clickers. While clicker companies may provide suggestions and training (T. Gordon, personal communication, March 28, 2019) along with schools (Arizona State University, 2018; Bruff, 2010; CWSEI, 2019; The Learning Center, 2019) there still will be a learning curve. Specifically, teachers must learn how to use the new feedback and results of the formative assessment to alter instruction actively throughout the class. This method is foreign to many instructors and some have expressed concern over this instruction method (Abrahamson, 2006; Hu et al., 2006). Although with appropriate execution, there is a gain in teaching efficacy (Hu et al., 2006).

Students. As students are unfamiliar with clickers and classroom discussions, some might feel that the discussion that stems from clicker questions is confusing and uses more class time than necessary (Draper & Brown, 2004; Nicol & Boyle, 2003). James & Willoughby (2010) observed a large proportion of discussion during a clicker question is underproductive or off-topic. This detracts from the usefulness of the discussion-based pedagogies and would lead students to think of the activities as a waste of time. While students may be encouraged to discuss a topic during a clicker exercise, this does not guarantee what the conversation will look like: some students may dominate conversations, others may not be able to participate, or students may be off-topic during the discussion portion of an activity (Hoekstra, 2009; Knight & Wood, 2005; Lantz, 2010; Nicol & Boyle, 2003; Vickrey et al., 2015). In smaller classrooms, there may be an opportunity for redirection, but in a classroom of 300, an instructor has no way to oversee all interactions. This poses a serious question to the efficacy of clickers and their subsequent discussions. With practice and experience, this effect does decrease (Reay et al., 2005).

The Future: Recommendations for Future Research and Development of Clickers

Using clickers to replace traditional response methods has an instrumental value. They can reduce the tedious work required in traditional classrooms. To better these effects, instructors need to be trained in the different uses of clickers and be made aware of the impacts these different uses have on students. To achieve payoffs in terms of student learning gains, instructors should use clickers in novel pedagogies. Many concerns are satisfied in these pedagogies. Therefore, researchers should focus on further developing and proving these methods and pedagogies. Specifically, researchers should study the differential impact of clickers on different student groups. Emerging research should aim to be more based on quantitative data. Studies should focus on learning gains compared through the different pedagogies and build upon the knowledge that discussion with clickers has positive benefits for students.

Addressing Research Concerns

Before moving forward addressing concerns discussed in prior sections, I will address concerns about clicker research. Researchers should vary the type or methods of research studies, extend the duration of studies, examine study participants, and reconcile differences in findings between studies. These critiques are not meant to discredit any prior work but are meant to provide insight moving forward, accounting for prior recommendations about the research.

From perception to student learning. The first concern, or reservation, about clicker research concerns the methodology of studies that draw positive conclusions about clickers. Fies and Marshall (2006) state that many studies rely mainly on anecdotal evidence. They conclude that further focus on opinions and student perception is unneeded. Many published studies conclude that students like clickers; future studies should focus on analysis. Studies should identify measurable effects on student achievement across different settings, pedagogy, and populations. Fies and Marshall also argue that current research superficially compares clickers and non-clicker classrooms. The research focuses on simply whether clickers are present or not, rather than assessing differing pedagogies and uses of clickers. Certain pedagogies are believed to improve student performance, but how do they compare against each other? Moreover, what are the best practices that achieve the highest learning gains within the pedagogies? These questions are examples of gaps in our understanding that future research should explore

Longitudinal work or long-term effects. Another concern centers on the lack of longitudinal work in clicker studies. Longitudinal work could examine classrooms after the introduction of clickers, rather than merely the initial impact of clickers. Much of the research that has been done with clickers focuses on the initial impacts of clickers in the classroom, ending studies with the last day of a class (Freeman & Blayney, 2005; Hatch et al., 2005; Mankowski, 2011; Martyn, 2007; Pettit et al., 2015; Walklet et al., 2016; Zeilik & Morris, 2004). Work that does attempt to cover clickers over long periods examines individual classes over multiple years (Aljaloud et al., 2015; Crouch & Mazur, 2001; Kay & LeSage, 2009), failing to follow students through multiple years of working with clickers. By only having studies of these initial impacts, the long-term effects of clicker use for students remain unexamined. For example, 70% of students enjoy clickers initially (Caldwell, 2007), and the teaching community interprets this reaction as a reason to use clickers. However, student perception after multiple years of working with clickers is unknown. At the undergraduate level, do freshmen, new to clickers, have a better perception of them than experienced seniors? Do the novelty and excitement wear off? More work that examines the effects of clickers on the same students over time would aid in furthering our understanding of how clickers affect students.

Inclusion and clicker use. For Trend 1, under student concerns, I briefly addressed a finding that around 30% of participants consistently report not liking or not seeing positive benefits from clickers (Caldwell, 2007). A limitation of the current literature is the inability to explain who makes up this 30%. While studies generally show that students like clickers, to forgo understanding the identities of those who do not like clicker is an error. Researchers need to be cognizant and purposeful in looking at the students who do not respond well to newly introduced classroom practices, aiming to not continue past inequities in education. Not enough is known about the specific effects of clickers on different demographic groups (Kay & LeSage, 2009, p. 826). Some work suggests a different impact of clickers by demographic groups.

The main body of this work focuses on gender. Angel Hoekstra (2009) performed a socio-cultural analysis of the effects of clickers in higher education. Student preferences for clickers exhibited some trends based on race and gender (Hoekstra, 2009). Her findings suggest that during clicker activities, male students are more likely to work independently, while female students prefer to work in groups for clicker questions. Females were more likely to float from group to group, rather than having a set group (Hoekstra, 2009). Also, male interviewees "were much more likely to mention or emphasize appreciating clicker questions as an opportunity to self-test" (2009, p. 128). Other studies have noted that females are more likely to enjoy and benefit from clickers (King & Joshi, 2008; Kang, Lundeberg, Wolter, delMas, & Herreid, 2012).

As with gender, there is research showing the differential effects of clickers by race and ethnicity. Hoekstra (2009) included some findings about cultural norms affecting students' performance in or perception of clicker activities, specifically when those cultures had norms around discussion/argumentation. One study explicitly explored race as a factor in comparing white students against underrepresented minority (URM) groups in Australia (Roberts & Diaz-Rainey, 2014). In classrooms where clickers were used, as well as in classrooms where clickers were not used, URM) students performed lower than their peers. These two studies begin to explore the relationship between race, ethnicity, and clicker use. This lack is surprising given the search and push for equity in education (Southerland & Gess-Newsome, 1999; "ASU charter," 2019).

Valuable findings from research on the difference between demographic groups more generally in education suggest the merit of doing this type of research. Gavassa, Benabentos, Kravec, Collins, and Eddy (2019) found that performance of students from different demographic groups varies across classroom style (online, hybrid, and in-person). Minority students, in general, performed worse in traditional lectures than other students. Further, minority students perform best in hybrid classrooms. A study on genetics identified the differential impact of current methods of teaching genetics (Donovan et al., 2019). Because of the methods of teaching, students overestimated actual genetic variability between different races. This furthers racial bias against certain URM groups with students attributing negative stereotypes as immutable traits due to genetics. The effect of this racial bias unequally and negatively impacts students who are from groups with negative stereotypes about capability, intelligence, or ability. A similar study explored the impact of "fixed-mindset" instructors on different student groups. Instructors with "fixed-mindsets" believe students are born with a certain level of academic prowess and that they cannot surmount this "natural" limitation. All students of instructors with this mindset perform lower than peers in other classrooms, but the instructor's mindset particularly impacts minority groups (Canning, Muenks, Green, & Murphy, 2019). These findings point to a need to look for differential impact in other areas of education, specifically the differential impact of clickers.

Increasing ability to compare clicker studies. Comparing studies without recognizing the impact of using new pedagogies, in addition to adding clickers, creates the false appearance that clickers only sometimes improve summative learning gains. Clicker studies cover a wide range of disciplines and assessment types. Probably, no one confounding factor explains the differences in learning gains between the different studies. However, in many of the studies that fail to find improvement in learning gains, the instructor did not implement discussion-based pedagogies along with clicker use (Anthis, 2011; Bunce, Flens, & Neiles, 2010; Karaman, 2011; Martyn, 2007; Paschal, 2002). As shown, students gain most when pairing clickers and peer discussion (Caldwell, 2007; Mazur, 1997; Judson & Sawada, 2002; Knight & Wood, 2005). Any effort to draw broad conclusions from the literature on clickers must consider technology uses and pedagogical approach.

Addressing Instructor Concerns

Instructors will choose whether to bring clickers into their classrooms. To expand beneficial clicker usage, they must see the purpose and benefits of using clickers. Addressing technology concerns and pedagogical concerns together enters the intersection of technical competence and pedagogical content knowledge, where the most benefits to the students and teachers are present.

Facility with technology. Instructors should not simply drop this technology into their classrooms. Teachers may have training available, but this does not guarantee instructors will use or take advantage of these resources. A strong recommendation is a teacher should comfortable with the technology before implementing it into a classroom. If instructors do not have the experience with clickers or at least a foundational knowledge of clickers, attempts to use them may be disruptive and result in the outcomes described under "no technical competence."

Clicker questions. Questions help fuel positive pedagogical practices; a shift can be observed to better outcomes when pedagogical content knowledge and technical competence complement each other to promote benefits for students and instructors. Still, instructors have concerns about numbers of questions, writing of questions, asking of questions, and what to do with feedback. While no one to my knowledge has specifically described a method for how to distribute clicker questions over class time, several authors address concerns about these questions. Caldwell (2007) draws on the works of Wit (2003) and Beekes (2006) to formulate a list of ways to improve questions and methods of questioning. Robertson (2000) also provides a very well written list of twelve tips for utilizing clickers, over half are about questions. Questions should be short, easy to read, and demand some level of confidence from students. Too often students can guess the right answer after identifying and eliminating obvious distractors. While this is a well-known test-taking strategy, when instructors ask questions in class to gauge learning and help them identify what material needs revisiting, strategizing responses hinders that goal. On using questions, Caldwell recommends instructors pair at least a few questions with the Peer Instruction pedagogy (Caldwell, 2007).

Content distribution. Another way to better distribute material and clickers is to have students engage with the material before class (d'Inverno et al., 2003; Fagen et al., 2002; Mazur, 1997). As discussed by Knight and Wood (2005), class time is not the time to introduce all-new material. In this model, instructors assign students material before class, and the class becomes a place to learn what students struggle with and focus on those key areas of misunderstanding. This approach is not without concern though. A recent study showed that only 70% of students study material before class (Brost & Bradley, 2006; Gooblar, 2014). This lack of student preparation would hinder this method of instruction. No suggestion is without flaws, but the perception of what clickers can do influences what ratio of material to questions is acceptable. If instructors view clickers as a way to uncover misconceptions and deduce what students need help with, they become indispensable. But, if an instructor's goal is to simply cover material, clicker questions are a waste of time. If the instructor combines clickers and proven pedagogies, they should see benefits and the time used well-spent.

New pedagogy and unfamiliar feedback. Instructors who have not used new pedagogy are going to have a period of learning, especially for using new feedback. Specifically, teachers must learn how to use the new feedback and results of the formative assessment to alter instruction actively throughout the class. This helps move the class forward to the ideal setting, but it does place a burden on the instructor. Many schools, as mentioned, have resources available for teachers, and training. Instructors must use these.

Addressing Student Concerns

While instructors bring clickers into their classrooms, students experience the deployment of the technology and ultimately their learning should be the reason behind classroom practices. Instructors and researchers should address students' concerns to reduce student resistance to clickers. This topic includes concerns about discussion, poor use of technology, the ability to ask questions, and worry about wasting time.

Technological problems and issues with the pedagogy hinder the effectiveness of clickers and push classrooms out of the ideal state and into the other outcomes.

Technology. While students may have individual issues with clickers during a class period, malfunction, or other occurrences, many of the technological concerns mentioned by students are instructor difficulties using clickers. Proper training of instructors will help mitigate these issues and move classrooms to the model where technological concerns do not detract from student learning or instrumental value for instructors. Students do need to become familiar with technology and classroom structure. Allowing students to practice activities at the beginning of the semester is one way to overcome this concern, as students adjust after a few uses (Arizona State University, 2018; Baer, 2015; Bruff, 2010; CWSEI, 2019; The Learning Center, 2019)

Testing. As noted, a portion of students do not like taking tests with clickers. A practical approach to address this issue would be to solicit student views before finalizing testing strategies. With clickers, instructors can poll students about views on taking tests with clickers. Another approach would be to reassess the need for high-stakes exams. For example, the pedagogies presented above emphasize using clickers for low-stakes, engaging activities rather than exams. Also, additional studies of the impact of using clickers for testing on students' willingness to use and preference for clickers would be valuable.

Attendance. I recommend finding other ways than clicker points to reward students for coming to class, and using clickers to increase student learning benefits, rather than using them as a tool to punish. For example, instructors can encourage students to come to class by using discussion and other engaging pedagogies to make it worthwhile for students to attend. Once students are familiar with clickers and know how to exploit them, cheating can occur. To mitigate this possibility, instructors can encourage academic honesty and remind students of the consequences of academic dishonesty. If there are discrepancies in visible attendance and response count, instructors can perform random checks of students' IDs to see which students responded but are not present. A physical sign-in may also help this process. These additional steps should only be taken if a problem with attendance becomes apparent as the extra activities detract from the benefits of using clickers.

Financial burden. Prices should be reduced before clickers become commonplace. As mentioned, the price can hinder access to education for some groups. Current developments in using smart devices as clickers may save students money and address this concern. However, about 75% of instructors only allow students to use dedicated clickers (T. Gordon, personal communication, March 28, 2019). Early findings suggest that, when students use alternative response devices, they may become distracted and utilize their devices for purposes outside the classroom (Bunce, Flens, & Neiles, 2010; Duncan, Hoekstra, & Wilcox, 2012). Further development of apps to reduce this potential could be valuable.

Student participation. As discussed, some findings suggest students verbally participate less after clickers are introduced. Future work should examine the effect clickers have on verbal questions for both systems in which students can ask questions and those without such capacity.

Student discussion. One way to manage student discussion meandering away from course topics is to use "moving and guiding" during discussion periods. Having

TAs or the instructor move through the class during discussion periods and monitor conversation helps focus students. Meaningful and engaging questions can also reduce off-topic discussion. Students who genuinely disagree because of a well-written question logically will be more inclined to discuss the topic. If questions fail to provoke disagreement students will have more reason to discuss other things. Quality pedagogy implementation enriches classrooms.

Conclusions and Implications

Instructors should continue to use clickers and researchers should continue to explore the effects of clickers. Clickers are by no means a perfect system. Since the development of clickers, instructors have struggled to use and integrate clickers into the classroom. With initial impressions low, but the promise of clickers having potential, their development and integration continued. The systems have become more cost-efficient and versatile. Instructors and researchers have adapted and developed methods of teaching, and now clickers can be found in major educational and business institutions across the world. Studies have identified different ways clickers can impact classroom participants. Studies have identified what some of the best ways to use clickers may be and some of the practices that should be avoided. Among the pedagogies that increase student benefits and learning, discussion is a common thread that links them. Figure 2 showcases the different classrooms/uses of clickers and their differing effects. The figure lists the different classroom types discussed in the present trends section, those that use novel pedagogy (gamification, peer instruction, cooperative learning) and those that do not, along the x-axis. The presence of clickers is listed along the y-axis. These axes form four paired sections which are: novel pedagogy that uses clickers, novel pedagogy that does not use clickers, no use of novel pedagogy with use of clickers, and no use of novel pedagogy without the use of clickers. Within each quadrant, there is a subdivision into the effects of students and the effects on teachers. Within each of the subdivisions are the applicable effects to the students or teachers.

Within the first quadrant, no novel pedagogy present with clickers present, benefits to students include “positive perception” (Bapst, 1971; Casanova, 1971; Chu, 1972; Garg, 1975), “immediate feedback” (Garg, 1975; Hatch et al., 2005; Heath, 2009; Paschal, 2002), “anonymity” (Garg, 1975), and “increased participation” (Paschal, 2002). The major drawback is that students do not like all the clicker practices (Caldwell, 2007). Notably, learning gains are not seen in this classroom. Instructor experience the logistical benefits of clickers (Garg, 1975; Heath, 2009; Paschal, 2002) but struggle with content balance during lecture (Caldwell, 2007).

The second quadrant, novel pedagogy, and clickers both present, shared many similarities to the classroom that does not have novel pedagogy in place and has added benefits. The effects like “positive perception” (Buil et al., 2019; Burnstein & Lederman, 2001; Caldwell, 2007; Crouch & Mazur, 2001; Gok, 2011; Nicol & Boyle, 2003; Pettit et al., 2015), “immediate feedback” (Beatty et al., 2006; Buil et al., 2019; Caldwell, 2007; Gok, 2011; Nicol & Boyle, 2003; Pettit et al., 2015), “anonymity” (Crouch & Mazur, 2001), and “increased participation” (Beatty et al., 2006; Beekes, 2006; Burnstein & Lederman, 2001; Caldwell, 2007; Draper & Brown, 2004; Gok, 2011; Nicol & Boyle, 2003; Pettit et al., 2015; Terrion & Aceti, 2012) are seen in both. What is new to this quadrant are the effects of “learning gains” (Barrio et al., 2016; Beatty et al., 2006; Caldwell, 2007; Crouch & Mazur, 2001; Nicol & Boyle, 2003) and “flow being achieved" (Buil et al., 2019). These key distinctions highlight the reason an instructor might choose to use a novel pedagogy with clickers, rather than sticking to the more traditional classroom. However, with new pedagogy come new issues. Students may be "unfamiliar" (Nicol & Boyle, 2003) or "misuse the discussion" portion of the class (Draper & Brown, 2004; James & Willoughby, 2010). Instructors face similar issues, but some are exacerbated. They still have the "logistical benefits" (Beekes, 2006; Burnstein & Lederman, 2001; Byrd et al., 2004; Pettit et al., 2015; Terrion & Aceti, 2012) but are required to spend "more time and effort" (Caldwell, 2007; Hu et al., 2006) on these discussion driving questions. It is also a "foreign method" to many instructors and as such, there is a learning curve (Hu et al., 2006).

The third quadrant is the classroom without novel pedagogy or clickers. Intuitively, there are "no benefits" of clickers and a sizeable amount of literature discusses the shortcomings of this classroom (Heath, 2009; Pelton & Pelton, 2006; Webking & Valenzuela, 2006). Importantly, the instructor is listed as experiencing "convenience" (Heath, 2009; Bostock et al., 2006) due to not needing to worry about the new technology or pedagogy.

The final quadrant represents a classroom where the novel pedagogy is present, but clickers are not. Again, there are similarities with another quadrant. Classrooms with novel pedagogy both with and without clickers have "learning gains" (Crouch & Mazur, 2001; Mazur, 1997; Fagen et al., 2002; Lasry et al., 2008; Miller et al., 2013; Schell & Butler, 2018), "positive perception" (Crouch & Mazur, 2001; Fagen et al., 2002; Lasry et al., 2008; Schell & Butler, 2018), and "increased participation" (Crouch & Mazur, 2001; Fagen et al., 2002). Without clickers, students lose some benefits, such as "anonymity."

The instructor loses the “logistical benefits” (Byrd et al., 2004; Crouch & Mazur, 2001; Lasry, 2008; Miller et al., 2013; Schell & Butler, 2018).

This matrix highlights that pedagogy is a driving force for learning gains, but that clickers do enhance the classroom; they support the pedagogy. There are many differing opinions about the value of clickers, as shown, but variation could be because of the large number of classrooms studied. Variability is something that needs to be considered during further research. It might benefit the body of literature to have a “baseline,” such as discussion, when studying clickers and their impacts. The matrix can also serve as a quick reference for instructors. By identifying where a classroom falls on the matrix and then comparing that to what effects an instructor wants in their classroom, it is relatively easy to identify the changes that need to be enacted. By no means is it easy to enact changes, but the figure provides an easy method to weigh the impacts of course design choices.

With improvements to clicker technology and pedagogy, the matrix may shift and change, hopefully improving each quadrant. Compared to the initial institution of clickers in the classroom, in terms of technology and its use, there have been substantial advances. Despite the advances in clickers and their use, concerns continue to be a prevalent feature of studies’ findings.

While many of the concerns have practices that either eliminate or quell their effects, some persist to cause issues. Lack of technological awareness and proficiency by instructors and students, lack of practice with systems, improper use of systems, and other operational deficiencies continue to be present but can be overcome. Recent work raised concerns that clickers may impact students differently. This literature begins to explore whether clickers can be used with differentiated instruction. While these studies advance our knowledge, a substantial percentage of students who dislike clickers remain (Caldwell, 2007). For clickers to continue, more must be understood about how they affect different groups and individuals over time. This conclusion led to the second part of this project: an original study meant to explore the impact of clickers on students.

		Novel Pedagogy	
		Not Present	**Present**
Clicker Technology	**Present**	**Students experience** **Positive Perception** (Bapst, 1971; Casanova, 1971; Chu, 1972; Garg, 1975) **Immediate Feedback** (Garg, 1975; Hatch et al., 2005; Heath, 2009; Paschal, 2002) **Anonymity** (Garg, 1975) **Increased Participation** (Paschal, 2002) **Dislike of Clicker Practices** (Caldwell, 2007)	**Students experience** **Learning Gains** (Barrio et al., 2016; Beatty et al., 2006; Caldwell, 2007; Crouch & Mazur, 2001; Nicol & Boyle, 2003) **Flow Being Achieved** (Buil et al., 2019) **Positive Perception** (Buil et al., 2019; Burnstein & Lederman, 2001; Caldwell, 2007; Crouch & Mazur, 2001; Gok, 2011; Nicol & Boyle, 2003; Pettit et al., 2015) **Immediate Feedback** (Beatty et al., 2006; Buil et al., 2019; Gok, 2011; Nicol & Boyle, 2003; Pettit et al., 2015) **Anonymity** (Crouch & Mazur, 2001) **Increased Participation** (Beatty et al., 2006; Beekes, 2006; Burnstein & Lederman, 2001; Caldwell, 2007; Draper & Brown, 2004; Gok, 2011; Nicol & Boyle, 2003; Pettit et al., 2015; Terrion & Aceti, 2012) **Unfamiliar** (Nicol & Boyle, 2003) **Misuse of Discussion** (Draper & Brown, 2004; James & Willoughby, 2010)
		Teachers experience **Logistical Benefits** (Garg, 1975; Heath, 2009; Paschal, 2002) **Content Balance** (Caldwell, 2007)	**Teachers experience** **Logistical Benefits** (Beekes, 2006; Burnstein & Lederman, 2001; Byrd et al., 2004; Lasry, 2008; Pettit et al., 2015; Terrion & Aceti, 2012) **More Time and Effort** (Caldwell, 2007; Hu et al., 2006) **Foreign Method** (Hu et al., 2006)
	Not Present	**Students experience** **No Benefits** (Heath, 2009; Pelton & Pelton, 2006; Webking & Valenzuela, 2006)	**Students experience** **Learning Gains** (Crouch & Mazur, 2001; Mazur, 1997; Fagen, Crouch, & Mazur, 2002; Lasry et al., 2008; Miller et al., 2013; Schell & Butler, 2018) **Positive Perception** (Crouch & Mazur, 2001; Fagen et al., 2002; Lasry et al., 2008; Schell & Butler, 2018) **Increased Participation** (Crouch & Mazur, 2001; Fagen et al., 2002)
		Teachers experience **Convenience** (Heath, 2009; Bostock et al., 2006)	**Teachers experience** **Lack of Logistical Benefits** (Byrd et al., 2004; Crouch & Mazur, 2001; Lasry, 2008; Miller et al., 2013; Schell & Butler, 2018)

Figure 2. Outcomes for students and instructors by possible combinations of clicker technology and novel pedagogy.

CHAPTER 3

ORIGINAL STUDIES EXPLORING THE POSSIBLE DIFFERENTIAL IMPACT OF CLICKERS

Instructors and researchers have shown that clickers can be used to enhance the student experience in science courses. But to fully appreciate the effects of clickers, a finer-grained analysis is needed to address a gap in the current literature. Possible differential impact of clickers on students from different demographic groups should be assessed. To provide some data toward achieving this goal, I performed a study built on prior work about perception (Mankowski, 2011; Martyn, 2007) and added metrics to learn more about the student participants. I aimed to analyze responses by different demographic indicators to view clicker perception trends within and between different demographic groups. The study originally was meant to run for a single semester, but, after errors were identified in the first period of data collection, a second data collection period was begun to correct these errors. The study was designed, both times, to be a pre-experimental study. The first data collection period included surveying a large enrollment upper-division biology and society course twice. The survey was first administered six weeks into the semester and it was repeated as an exit-survey in the final week of instruction after students spent a semester using clickers in. Due to pre- and post-surveys not being linked in this first study design, only the exit-surveys were analyzed. From this study, I was able to compare the mean responses from different demographic groups and view the composition of the groups of students that responded negatively to clickers. The second round of data collection was begun during the following semester in a smaller biology and society course. It was planned to have pre- and post- linked surveys to look at changes in student perceptions of clickers over the semester across different demographic groups. Unfortunately, this study was interrupted by the global COVID-19 pandemic. So, I will only report on the study design and not results. This research is preliminary in the sense that it involves only a small study population and is more exploratory in nature, rather than seeking explanations for any differences that may be observed. The knowledge obtained from this preliminary research could help guide future research in the field to address these concerns. I hope it will inspire others to look deeper and continue this work in a systematic and meaningful way. The first study in this manuscript was reviewed by Arizona State University's IRB and found exempt under the Study ID 00010589 and was approved on 9/17/2019. The second study was submitted as a modification to the first and was approved on 1/31/2020. Both studies were conducted per the approved protocol.

First Study: Pre-Experimental Exit Survey

Purpose. To explore the relationship between students' perception of clickers and the demographic groups they belong to, I surveyed science students in a large enrollment upper-level college biology and society course. This class used clickers in a variety of ways, using methods from novel pedagogies and tools for enhancing the classroom. Students were asked six weeks into the semester and at the end of the semester to fill out a perception instrument on clickers. The study was conducted in this manner to view the perception change, if any, over the course of the semester. Demographic data was collected and used to see if there were any correlations between different demographic factors and student perceptions. From the students' responses, I was also able to examine the students that responded negatively, to try and view more closely the composition of the group that does not respond positively to clickers as noted in prior work (Caldwell, 2007).

Recruitment. In Fall 2019, I administered both surveys to approximately 140 undergraduate students in one upper-level large-enrollment biology and society course at a large public research university in the United States. All students enrolled in the course were given an information letter and a short statement was made about the study, reiterating the main points in the letter. Time after that class period was provided for students to ask questions and receive clarification. Students were told explicitly and repeatedly that participation would in no way change their grades in the class. The first survey was administered six weeks after the semester began after an exemption was granted by the IRB. The second survey was administered during the final week of normal instruction for the Fall semester at the end of the class, the week before finals. Those who chose to complete the surveys could anonymously submit the surveys as they exited. Students were thanked with a cookie for turning in a survey. 106 surveys were collected from the first survey. 80 surveys were collected from the second survey.

Measures. To measure student perception of clickers, I used a survey instrument developed and used in two prior studies that explored student perception of clickers. The original instrument was designed to be used to compare a class that used clickers with a discussion-based course. Because of this design, there were two survey versions, one asking about clickers and the other about class discussion. In this study, only the clicker version was used (Mankowski, 2011; Martyn, 2007). The original survey did not include any questions about demographics or tools to learn about the students who respond to the survey. As the point of this research was to look for possible differential impact, a demographic section was added. The demographic section used typical census-styled questions on gender, race/ethnicity, and age. Outside of these questions, I included two more questions to allow for further exploration about students' identities. These included one question about whether students were first-generation college students and another on whether they had prior experience using clickers. The final instrument consisted of two sections. The first section was composed of the demographic questions where students indicate the identifiers that best fit them. The second section consisted of items that addressed student perceptions in a course using clickers. Students responded to five-point Likert-type items from strongly disagree–strongly agree. This part of the instrument comes from prior studies by Martyn (2007) and Mankowski (2011). The questions focused on students' perception of their grades, understanding related to the subject, belonging, interaction with the instructor, interaction with other students, their enjoyment, and their recommendations for future use of clickers in the course. Question 11 (Enjoyment of Clickers) was used to view the composition of the group that responded "Disagree" or "Strongly Disagree," exploring the consistent group of students that do not like clickers as discussed by Caldwell (2007).

The measure, included as Figure 3, was administered in paper format to all the students. Students were given class time to complete the survey and on completion turned it into receptacles at the doors when exiting the class. The data was entered manually from each of the surveys into a Windows 2016 Excel spreadsheet and then transferred to IBM SPSS 25 for data analysis. The analysis consisted of five independent ANOVA's for each of the demographic questions, aimed at looking for differences between demographic groups in the way they responded to each of the items.

***Limitations of this study*.** This data collection period initially included a pre- and post-surveys for students. Although I did administer both surveys, the six-week survey and end of semester survey, a system for linking pre- and post- surveys between students was not put in place. This decision means that, while the surveys were completely anonymous, I was unable to look at whether individuals changed their views over time. When taking averages of the pre- and post- without having students linked, the results may be misleading. Students will have differing opinions of clickers going into a study, especially considering prior experiences. These pre-surveys serve as a chance to flush out the variance that will inherently be in the data set. Without the link, they cannot be used for this purpose.

Due to there being no matched pairs, common tests that require this to account for variance such as dependent-samples t-tests and repeated measures could not be used (Shavelson, 1996). To conduct other forms of analysis, I would need to account for the lack of independence. Because I conducted a pre- and post- assessment, my data is not independent as the post-results are directly connected to the pre-results. For these reasons, the post-survey is viewed independently of the pre- results as a singular exit-survey meant to broadly gauge students' opinions of clickers. It is pre-experimental, so definitive conclusions about trends found in the data cannot be drawn. It serves in a preliminary role to inform generally about what students feel about clickers, but not clickers as a treatment.

Clicker Perception Survey

Please circle the best option

1. What is your gender?

   a) Male b) Female c) Other d) Prefer not to answer

2. What is your age?

   a) 18-24 b) 25-40 c) 40 or older d) Prefer not to answer

3. What is your race/ethnicity?

   a) White b) Black/African American c) American Indian/Alaskan Native
   d) Asian e) Pacific Islander f) Hispanic
   g) Other h) Prefer not to answer

4. Are you a first-generation college student?

   a) Yes b) No c) Prefer not to answer

5. Have you used clickers before?

   a) Yes b) No c) Prefer not to answer

For the following statements, please indicate how much you agree with each statement.

1 = Strongly disagree; 2 = Disagree; 3 = Unsure; 4 = Agree; 5 = Strongly Agree

6. Participation with clickers improved my grade in the course.

   1 2 3 4 5

7. Participation with clickers improved my understanding of the subject content.

   1 2 3 4 5

8. Participation with clickers increased my feeling of belonging to this course.

   1 2 3 4 5

9. Participation with clickers increased my interaction with the instructor.

   1 2 3 4 5

10. Participation with clickers increased my interaction with other students.

    1 2 3 4 5

11. I enjoyed participation with clickers.

    1 2 3 4 5

12. I would recommend using clickers again in this course.

    1 2 3 4 5

Figure 3. This is the survey instrument that was given students. The first section comprises questions about the student (1-5) and the second set of questions is meant to gauge the students' perception of clickers (Mankowski, 2011; Martyn, 2007)

***Analysis*.** After data collection, only 79 surveys were able to be used for analysis as one student's results were omitted due to the student being under the age of 18. The analysis was conducted where each of the demographic questions served as an independent variable with varying factor levels depending on the specific question. The analysis was run this way so that a simple one-way ANOVA could be utilized for each of the demographic indicators. I used SPSS 25 to run five individual tests, one for gender, age, race, first-generation status, and prior clicker use and used questions 6-12 as the dependent variables. By using ANOVA, I am making certain assumptions about the data. Those assumptions are: each group sample is drawn from a normally distributed population, all populations have a common variance, and all samples are drawn independently of each other. With only an exit survey, responses are independent as they each provide a unique contribution to the data independent of each other. Admittedly, using Likert-type items could be viewed as incorrect by some academics (Jamieson, 2004). Because Likert-type items use a fixed scale they are viewed as an ordinal level of measurement. This causes a cascade of questions when using ANOVA to understand the differences between the data as it uses an interval level of measurement. When transcribing the ordinal data to interval data, there are assumptions made about the data and inconsistencies that need to be addressed (Jamieson, 2004). Firstly, in the data there is a lack of normality. Simply put, ordinal data is not continuous as it sits on a set scale. To mitigate this, rather than look at the individual points, I observe the means of the groups, which is on a continuous scale and is fit for parametric tests (Norman, 2010).

Another issue arises when looking at the homogeneity of variance. ANOVA is robust to violation of this assumption, except in cases where there is an unequal number of subjects in each of the groups (Shavelson, 1996). Because of the nature of my study, there are differences between the groups. This combined with the concerns about normality seems to question the validity of the study. In ANOVA though, homogeneity of variance and normality assumptions can be relaxed if the sample meets certain criteria. To relax assumptions of normality, the sample size should be relatively large. Having 30 participants is cited as a good initial size, but the more participants the better, as more participants will help fulfill the Central Limit Theorem (Shavelson, 1996, pp. 255–259). The sample size is large, but I will still be careful when interpreting results where group sizes are not equal, as in these cases a few students can drastically shift the results. Also, when having a finite number of levels for independent variables assumptions can relax for normality and homogeneity of variance. ANOVA is robust in this circumstance (Norman, 2010).

As I am using ANOVA, I must be cognizant of Type 1 (false positive) error rates. Since multiple hypotheses are being tested, Type 1 error rates may be inflated. To counteract this, I will use alternative alpha levels that compensate for this increase through post-hoc testing. I will use Bonferroni corrections, which adjust the significance level higher according to how many comparisons are being, accounting for error (E. Sloat, personal communication, February 14, 2019). I do note that Tukey post-hoc tests might be preferable because they are more statistically powerful when compared to Bonferroni corrections. I decided to use Bonferroni corrections since I understand how they work better and can more confidently interpret the results.

To look at effect size for the significant results, I used Cohen's d. SPSS does give eta-squared in its readout, but due to concern about the bias of eta-squared, especially when group sizes are small, I decided against using this. Omega-squared could have been an alternative, as it can mitigate the bias caused due to small groups (Skidmore & Thompson, 2013). For simplicity, especially considering that there were only a handful of significant findings and they were under "Age" which only had three sub-groups, I opted to use Cohen's d. Since Cohen's d uses standard deviation, this will provide the size effect using the standard deviation of the samples (Shavelson, 1996). I used the equation $d = \frac{M_1 - M_2}{SD_{pooled}}$ with SD_{pooled} being calculated with the equation $SD_{pooled} = \sqrt{\frac{SD_1^2 + SD_2^2}{2}}$ (Cumming, 2013). In this case, I pool the SD as it is assumed the groups have the same deviation being from the same population (Cardinal & Aitken, 2006). Interpretation of effect size is based on Cohen's suggestion that d=.2 is considered a 'small' effect size, d=.4 is considered a 'medium' effect size, and d=.8 is considered a 'large' effect size (Cardinal & Aitken, 2006; Shavelson, 1996). To supplement the significance findings, I will provide the actual means from each of the groups to perform visual comparison and look for trends.

As one of the driving influences for conducting this study was the "30% of students" who dislike clickers as identified by Caldwell (2007), the analysis also included a review of the students in this study who responded "Disagree" or "Strongly Disagree" to Question 11 on the instrument (i.e., "I enjoyed participation with clickers"). The group was separated based on the different demographic indicators and percentages of these students as a portion of the total demographic group they identified. The way this group responded to the other questions on the instrument was also examined to look for any interesting trends.

Results. The first ANOVA was run for gender, this is of special interest considering the past literature that observed and reported differences between how males and females respond to using clickers (Cheesman et al., 2010; Kang et al., 2012; Kiefer, 2013; King & Joshi, 2008). Despite these past findings, in this preliminary pre-experimental survey I observed no statistically significant difference in exit opinions between the genders using a 95% confidence interval. Table 1 provides the F-statistic and significance for each of the questions. Through this report, I fail to reject the null hypothesis, that there is no difference between the ways students respond based on gender. For this comparison, I was unable to apply a Bonferroni adjustment because one group only had a single member. SPSS 25 will not run post-hoc tests for 2 groups even when performing multiple univariate analysis, which can inflate the familywise error rate. This would be a consistent occurrence as many of my independent variables only have 2 groups compared over multiple variables. For this reason, I gave extra attention to effect size when looking at the significant findings. I also interpreted all findings as tentative until they are supported by other literature and more robust studies (Feise, 2002; Huberty & Morris, 1989). To further explore data, outside of significance, I compared trends in the means. This data can be found in Table 2. Per the table, the females' mean was higher than the males for five out of the seven questions. The differences between the means varies widely, but, interestingly, males had a smaller mean than the females most of the time. The "Prefer not to answer" group only had one participant, but they responded in agreement for each item.

Table 1

ANOVA Results for Gender

Question:	F-statistic	Significance (P-value)
6 (Grade Improvement)	.739	.481
7 (Understanding of the Subject)	2.140	.125
8 (Feeling of Belonging)	1.323	.272
9 (Interaction with Instructor)	.027	.973
10 (Interaction with Students)	1.465	.238
11 (Enjoyment of Clickers)	1.096	.340
12 (Recommend Clickers for Future Classes)	1.337	.269

Table 2

Means of Gender Groups

	Question:						
Gender:	6	7	8	9	10	11	12
Male	3.52	3.31	3.97	3.93	3.93	3.55	3.72
Female	3.57	3.73	3.65	3.88	4.31	3.82	4.06
Prefer Not to Answer *	5.00	5.00	5.00	4.00	5.00	5.00	5.00
*Group only had 1 student							

Another category of interest in prior literature is age (Cheesman et al., 2010). When running the ANOVA for age, some questions were tagged as significant (Table 3). Question 8 (student's feeling of belonging) had an F-Statistic of 4.891 and a p-value of .010. The effect sizes for the different pairs were: .840 for the groups of 18-24 and 25-40 which can be interpreted as a large effect size, 3.647 for the groups 18-24 and 40+ which can be interpreted as a large effect size, and 5.695 for the groups 24-40 and 40+ which can be interpreted as a large effect size. Question 11 (student's enjoyment of clickers) had an F-statistic of 3.067 and a p-value of 0.052. This p-value is close to the .05 cut-off, on the precipice of significance, and in an n-count that is small, a minor error could shift the value either way. The effect sizes for the different pairs were: .146 for the groups of 18-24 and 25-40 which can be interpreted as a small effect size, 3.545 for the groups 18-24 and 40+ which can be interpreted as a large effect size, and 2.740 for the groups 24-40 and 40+ which can be interpreted as a large effect size. Question 12 (Recommendation for future clicker use) had an F-statistic of 3.940 and a p-value of .024. The effect sizes for the different pairs were: .009 for the groups of 18-24 and 25-40 which can be interpreted as a small effect size, 4.039 for the groups 18-24 and 40+ which can be interpreted as a large effect size, and 3.463 for the groups 24-40 and 40+ which can be interpreted as a large effect size.

Table 3

ANOVA Results for Age

Question:	F-statistic	Significance (P-value)	Cohen's d**		
			1 & 2	1 & 3	2 & 3
6 (Grade Improvement)	2.428	.095	.000	3.228	2.198
7 (Understanding of the Subject)	2.880	.062	.183	3.329	4.731
8 (Feeling of Belonging)	4.891	.010*	.840	3.647	5.695
9 (Interaction with Instructor)	.938	.396	.529	3.821	5.378
10 (Interaction with Students)	2.636	.078	.367	4.474	3.830
11 (Enjoyment of Clickers)	3.067	.052*	.146	3.545	2.740
12 (Recommend Clickers for Future Classes)	3.940	.024*	.009	4.039	3.463

*Significance found on a 95% confidence interval **This section is divided into groups (18-24 is Group 1, 25-40 is Group 2, Over 40 is Group 3) as Cohen's d only compares the means of two groups at a time.

Due to the extremely large effect sizes, especially considering the difference between the first pairing and the subsequent pairings that include the "Over 40" group, I decided to investigate further. I generated Q-Q plots for the data and used the "Explore" feature to identify outliers. It was found that one student was marking 1's for each question. They were the only student in the 40+ range. When running the data set without differentiating between groups, the student was marked as an outlier. Upon removing him from the data analysis, an independent t-test was performed. All the significant findings were no longer significant, as seen in Table 4. Similarly, to the gender demographic, since there were only 2 groups after removing the 40+ group, SPSS would not allow for post-hoc testing and the same principles apply to age and the rest of the demographics.

As this is a parametric test, it is extremely sensitive to outliers. In removing the data, this shows that this student plays a major role in creating a significant association. Upon further review of this student's responses, they responded 1 to all the questions. A unique feature of this group is that there was only one student. Although for most students I could not link the pre- and post-surveys together, because this student was the only respondent over 40+ his surveys could be compared. I viewed his pre- and post-test and for both surveys, he only responded with 1's. Considering this, I feel that is important to report the data with and without this student being included. Means are provided for each of the groups for comparison outside of the significance testing in Table 5. It is visible that the 40+ student did not respond positively to clickers. By looking at the means though, this did not hold true for the 25-40 group. This group had scores like the 18-24 group and in many items had a more positive response. This knowledge helps to show the impact the single student had on the initial ANOVA.

Table 4

Independent Samples T-Test Results for Age excluding 40+ group

Question:	t-statistic	Significance (P-value)	d
6 (Grade Improvement)	.005	.966	0.000
7 (Understanding of the Subject)	-.361	.719	.183
8 (Feeling of Belonging)	-1.691	.095	.840
9 (Interaction with Instructor)	-1.070	.288	.529
10 (Interaction with Students)	.902	.370	.367
11 (Enjoyment of Clickers)	.349	.728	.146
12 (Recommend Clickers for Future Classes)	-.028	.978	.009

Table 5

Means of Age Groups

	Question:						
Age:	6	7	8	9	10	11	12
18-24	3.60	3.62	3.77	3.88	4.23	3.78	3.99
25-40	3.60	3.80	4.60	4.40	3.80	3.60	4.00
40+*	1.00	1.00	1.00	1.00	1.00	1.00	1.00
*Group only had 1 student							

Continuing with the demographics, race/ethnicity was used as the independent variable in the next ANOVA. While I did not find specific prior literature dedicated to this relationship, I thought that this would be an important area to study based on my reading about equality in education and science education. Despite my thoughts, there was no statistical significance found when running the ANOVA. Table 6 provides the results from that ANOVA. Again, based on the findings, the null hypothesis cannot be rejected. As this ANOVA has multiple groups with more than 2 people, I was able to run Post-Hoc testing. Two groups were excluded because they only had a single member in the group. The Bonferroni adjustment showed no significance for any of the questions, confirming the results from the ANOVA. Despite this finding, I again looked at the means from each group and how they compared, outside of significance (Table 7). At first glance, some groups have very high ratings. Like in prior indicators, some groups only had one person which lead to these extremely high ratings. White students responded with lower ratings on items when compared to the other race/ethnicity groups, outside of the “Prefer not to answer” group. The Asian, Black, and Hispanic groups were the three highest responding groups, in that order. To look explicitly at how they compared, I added the means across the questions. The Asian group had a total of 28.67, the Black group had a total of 28.61, and the Hispanic group had a total of 28.5. While these were very close, all were higher than the White group, a total of 25.45.

Table 6

ANOVA results for Race/Ethnicity

Question:	F-statistic	Significance (P-value)
6 (Grade Improvement)	1.428	.208
7 (Understanding of the Subject)	.468	.854
8 (Feeling of Belonging)	1.348	.241
9 (Interaction with Instructor)	1.016	.428
10 (Interaction with Students)	.251	.970
11 (Enjoyment of Clickers)	1.220	.303
12 (Recommend Clickers for Future Classes)	.990	.445

Table 7

Means of Race/Ethnicity Groups

	Question:						
Race/Ethn-icity:	6	7	8	9	10	11	12
White	3.28	3.50	3.58	3.78	4.08	3.50	3.73
Black	4.33	3.67	4.00	4.00	4.33	4.00	4.17
American Indian*	4.00	3.00	4.00	5.00	4.00	4.00	5.00
Asian	4.17	3.67	4.33	4.00	4.00	4.17	4.33
Pacific Islander*	3.00	5.00	4.00	5.00	5.00	5.00	5.00
Hispanic	3.89	3.67	4.22	4.11	4.33	4.11	4.28
Other	3.60	4.00	3.40	4.00	4.20	3.60	3.60
Prefer Not to Answer	2.50	3.00	2.50	2.50	4.50	2.50	3.50
*Group only had 1 student							

First-generation and prior clicker use were both added as extra metrics to measure against. Both optics did not show statistical significance for any of the questions. The findings for First-generation status and prior clicker use are provided in tables 8 and 10, respectively. Like with the rest of the metrics, means are provided in tables 9 and11, respectively. When looking at these metrics to see who had the higher mean, for both questions, there was a 4 to 3 split. None of the groups from either item was consistently higher or lower than the others. These were the closest pairings out of all the metrics.

Table 8

ANOVA Results for First-Generation Status

Question:	F-statistic	Significance (P-value)
6 (Grade Improvement)	.576	.450
7 (Understanding of the Subject)	.001	.979
8 (Feeling of Belonging)	.263	.610
9 (Interaction with Instructor)	.316	.576
10 (Interaction with Students)	.010	.922
11 (Enjoyment of Clickers)	.242	.624
12 (Recommend Clickers for Future Classes)	.026	.873

Table 9

Group Means of First-Generation Groups

	Question:						
First-Generation Status:	6	7	8	9	10	11	12
Yes	3.72	3.60	3.88	3.31	4.16	3.64	3.92
No	3.50	3.59	3.74	3.94	4.19	3.78	3.96

Table 10

ANOVA Results for Prior Clicker Use

Question:	F-statistic	Significance (P-value)
6 (Grade Improvement)	.745	.391
7 (Understanding of the Subject)	1.011	.318
8 (Feeling of Belonging)	.574	.451
9 (Interaction with Instructor)	1.119	.293
10 (Interaction with Students)	.039	.843
11 (Enjoyment of Clickers)	.014	.905
12 (Recommend Clickers for Future Classes)	.417	.520

Table 11

Group Means of Prior Clicker Use Groups

	Question:						
Prior Clicker Use:	6	7	8	9	10	11	12
Yes	3.62	3.65	3.74	3.95	4.17	3.73	3.71
No	3.31	3.31	4.00	3.62	4.23	3.77	3.77

While there was not a lot of significance found when running ANOVA for any of the demographic metrics, there were some encouraging findings. Speaking to the initial question regarding the consistent percentage of students who dislike clickers, in the survey, 15.2% of respondents say they did not like clickers being used to participate in class. This matches the consistent percentile that I observed in many of the perception studies I viewed, although it is lower than Caldwell's generalized 30% (Caldwell, 2007). The composition of this group is broken down in Table 12. When looking into this group of students, specifically with the question related to whether the students enjoyed clickers being used in class, there was an even split of 6 females and males. In sheer numbers, this is equal, but by percentage, 20% of all males in the class answered that they "Disagree" or "Strongly Disagree" compared to 12% of the female students. While the mean of each group was not significantly different, a greater percentage of the male cohort responded "Disagree" or "Strongly Disagree" than their counterparts in the female cohort. Again, while the means were not significantly different, this was meant to explore the composition of the group of students who did not like clickers. These findings are more reminiscent of the findings in the literature I read, where there was a difference in response between males and females (Hoekstra, 2009).

Table 12

The Make-Up of the Group that Responded 1 or 2 to Question 11 (Enjoyment of Clickers)

Gender:	Age:	Race/Ethnicity:	1st Generation student:	Prior Clicker Use:
6 Males 21%	10 "18-24" 14%	9 White 23%	4 Yes 16%	10 Yes 15%
6 Females 12%	1 "25-40" 20%	1 Hispanic 6%	8 No 15%	2 No 15%
	1 "40+" 100%	1 Black 17%		
		1 Prefer Not to Answer 50 %		

Table 13

Responses by Students from Q11 Group to Other Questions

	Rating				
Question	"Strongly Disagree"	"Disagree"	"Unsure"	"Agree"	"Strongly Agree"
6 (grade improvement)	2	5	4	0	1
7 (Understanding of subject)	2	4	3	3	0
8 (Feeling of belonging)	3	2	4	2	1
9 (Interaction with instructor)	2	1	3	6	0
10 (Interaction with students)	1	3	1	6	1
11 (Enjoyment of Clickers)	4	8	0	0	0
12 (Recommend future clicker use)	3	4	4	1	0

Including the other factors, the composition of the group of students who answered 1 or 2 is shown in Table 12. Of the 12 students, 6 were female and 6 were male, 10 were from the age 18-14, 1 from the 25-40 range, and 1 who was 40+, 9 students were white, 1 was Hispanic, 1 was Black/African American, and 1 preferred not to answer, 4 students were first-generation and 10 had used clickers previously.

A surprisingly high percentage, 100%, is found in the age section, due to the previously discussed single student who was above the age of 40. There was a similar occurrence in the Race/Ethnicity demographic. 2 students responded as "Prefer Not to Respond" and 1 marked that they did not enjoy clickers, hence the 50% observed in Table 7. Those students who self-identified as Hispanic had the lowest percentage of negative responses (6%). The percentage of students for the first-generation status was nearly identical and the percentages of students for prior clicker use were identical.

Further exploring this group of students, their responses to the rest of the questions were tabulated. The results are presented in Table 13. An area of special interest, due to the large proportion of agreement, was questions 9 and 10 which deal with interaction, 50%, and 58.3% respectively. These questions had the highest agreement of the other questions. Question 6, asking about grade improvement, had one student who strongly agreed. Question 7, asking about the understanding of the subject, had three students who responded that they agree. Question 8, exploring students' feelings of belonging, had 2 students respond that they agree and one student who responded that they strongly agree. Question 12, the question asking about the agreement to the use of clickers in a future iteration of the course, surprisingly one student responded that they would agree.

In summary, the findings for the ANOVAs generated for gender, race/ethnicity, first-generation status, and prior clicker use fail to reject the null hypothesis that there is no statistically significant difference in how students of the different demographic groups respond. There were a handful of statistically significant p-values generated when running an ANOVA for Age. Upon further exploration, it was found that one student, identified an outlier by the program, seemingly was responsible for these findings. When excluding this student and then running a t-test on the remaining groups, no statistical significance was found. I would, out of caution, fail to reject the null hypothesis that there is a difference in student's responses. When looking at the composition of the group of students who marked that they did not enjoy clicker use, I observed that there is a higher percentage of the male student body in the group. When further studying these students' responses, a majority agreeing that clickers increase interaction with the instructor/students. The comparison of means showed that males consistently have lower means across all items when compared to females. When looking at race, white students consistently had lower means, while the other groups had similar, higher means. The responses by the other groups were very similar. Between the ANOVA, means, and the composition of the highlighted group, there is agreeance and conflicting ideas. Considering this, how can these findings be interpreted?

Discussion. In recap, through the omnibus ANOVA run for each of the demographic items and the items only one area was initially tagged as being statistically significant, "age." When looking further at the data and manipulating it, it was found that by removing one student group, comprised of a single student, the p-values no longer indicated significance. It becomes especially interesting when looking at the size of the effect. The pairings of the 40+ group with the other groups had large effect sizes for each question. This is because Cohen's d uses a pooled standard deviation to look at the differences between the means. With a mean score of 1 on every question, it compares to the composite mean derived from multiple respondents of the other groups. This helps to explain the large effect sizes. When comparing the other 2 groups, the effect sizes are not as large. This further contributes to why data was provided excluding that student group.

Despite failing to reject the null hypothesis, based upon the statistical analysis, the findings of the study should not be interpreted as proof that there is no interaction between students' identities and their opinions and response to clickers. This is especially true when considering the limited pre-experimental design and the inherent limitations of the study. Even if there were statistically significant differences for multiple demographics and questions, there would still be some reservations in claiming that clickers were the cause of this difference, citing the earlier discussion about the limitations in this study. Because the data reflects solely a singular point in the final week of instruction for the semester, without any control for prior opinion, experience, or feelings, changes that may have occurred over the semester are not visible. The data show the "finish line" results without descriptors of arriving there. So, the question becomes what has been learned?

First, areas to be mindful of have been identified. Although age had varying results, the sample size was too small to make any concrete conclusion. For instance, I wonder what including more data from multiple students over 40 would do for the data. This sample was so small that one student had a large pull on the significance, it would behoove future researchers to find more students for each of the groups, seeking to find meaningful significance. While technology may be more familiar to the upcoming students, those students who are starting school later in life or are returning to school for a change might not be as keen to experience new technologies. Returning to the findings of the studies in the literature that discussed age, these adults were educators or tied to education (Cheesman et al., 2010). This very well could influence their opinions. It would be fruitful to purposefully look at older students who are in undergraduate STEM classes. A concern is that these students represent a relatively small part of the student body, but this does not diminish the need to think about them and their learning. In the study, the fact that the only student who was over 40 responded consistently in the negative is something to be cognizant of. One of the five students who self-identified as being from the age of 25-40 responded similarly to the 40+ student. Combining the two groups shows that ~33% of the students over 25 did not rate clickers highly. When looking at the entire 25-40 group, surprisingly to me, the responses from the 25-40 students have higher means across the questions when compared to the 18-24 group, save question 11 about enjoyment. This outcome would suggest that age did not have a bearing, since the older students rated their experience with clickers, on average, higher. These two conflicting views help show another limitation of this study. Because the sample size was so small, I am hesitant to make any definite conclusions about age and clickers. A bigger sample size would be needed to more accurately and precisely determine if there is an effect. While these are small subgroups, it shows that further thought may need to be given to how age and its related effects (changes in perception, comfort with technology, social status, confidence, etc.) might affect students and their perception of clickers. In short, age and clicker perception going forward should be an area of interest. This is not the only interesting conclusion that can be drawn from the data.

Gender has been shown in the literature to have some effect on student response to clickers, as females seem to have a more positive perception of clickers while males preferred traditional lecture classes (Hoekstra, 2009). There was no significance found in this one-shot exit study, but again this does not mean that there is no relationship. When looking at the trends in the means, males responded less positively to clickers on every question when compared to females. Although the means were not significantly different, it is compelling that the females always rated the instrument items higher. This seems to align with the prior work that noted males did not care for clickers as much as females. This becomes even more apparent when looking at the group of students who responded that they dislike clickers, a trend emerges that fits more within the prior findings. 21% of all the males in the class responded that they either "Disagree" or "Strongly Disagree" with the statement that "I enjoyed participation with clickers" compared to 12% of all females responding similarly. By these metrics, males were twice as likely to respond this way, one in five males compared to one in ten females. This finding echoes the findings that males may not be as enthusiastic about using clickers in class, preferring more traditional lectures (Hoekstra, 2009; Kang et al., 2012; Kiefer, 2013; King & Joshi, 2008). This is not definitive or comprehensive study but is compelling when added to the prior arguments and findings.

My personal interest led me to ask about the relationship between student perception of clickers and race/ethnicity. Prior work has focused on culture affecting students' responses and touched on the interaction of ethnicity and clickers (Hoekstra, 2009). Another study looked at Maori and Pacific Island students at an Australasian university trying to see if they had the same level of attainment in a clicker classroom, which they did not (Roberts & Diaz-Rainey, 2014). Generally, there is a lack of work about clickers and race/ethnicity. To provide some more information to the discussion, I included race/ethnicity in the first section and then compared to see if races responded differently. The ANOVA showed no significance in the differences of the means between the groups. When looking at the means, however, there are some visible trends. Notably, white students had a smaller mean for each of the questions when compared to Black/African American, Hispanic, or Asian students.

This was another surprising trend that was not apparent through the initial statistical tests, and an example of why more work in this area would be beneficial. If white students are less enthusiastic about clickers, how can their continued use be justified? Is there definitive improvement in student performance that warrants the use despite dislike? Would it be equitable to use clickers when the minority students rated them higher than the white students generally? An even simpler question might ask why this was the case in this study? I did not use interviews or open response questions, which might have provided valuable insight into the "why" of the responses. More work looking at this relationship and using other instruments to uncover why students responded the way they did and comparing the responses across demographics would be valuable.

Since this is a small pre-experimental study, I cannot make large conclusions, but I can say that this finding, paired with the limited prior works shows that it is a relationship worth exploring. My study repeatedly illuminates a need for bigger, more expansive studies to explore what I have scratched the surface of.

When I was looking at the initial ANOVA results, I thought that it was simple enough to see that there is not a difference between any of the demographic groups' responses to any of the questions. The use of means helped to redirect this line of thinking, along with looking at the students, as individuals, who responded that they did not like clickers. These methods helped me to ask more why questions and to recognize trends in my data that I did not see at first glance.

In the study, I directly answered the question about the composition of the group of students was who said they do not like clickers. This simple addition to perception studies is worth the effort as it begins to look at which students might not like clickers. This study by no means provides a definitive answer to what the composition of this group looks like generally. More studies would need to be completed to provide more data to understand the larger picture. A compelling finding from this limited look is that of the students who openly responded that they dislike the use of clickers, a majority still agreed that clickers increase their interaction in class. This might seem intuitive, that when you use discussion-based clicker activities students discuss and interact, but it is telling that students recognize that class is no longer a passive exchange of information. If an instructor wants to increase student interaction and get students talking with each other, using clickers will do that. An important addition to the prior statement might be, "Whether students like it or not." For students to recognize the increased interaction and say that they do not care for participation using clickers, it raises the question of why they are not responding positively to the perceived benefit. If the work around gender holds true, males may recognize the increased interaction but out of preference for the traditional lecture, may respond negatively. This dynamic should start a discussion of why students do not like using clickers, rather than just the polar question of “Do you like them or not?” This survey did not give students the chance to respond in their own words, so I do not have a contribution toward understanding the reasons for students’ perceptions. A method that would allow students to respond would be valuable but was not planned in this project. As mentioned, this pre-experimental study had many areas that could have been improved on, especially design limitations.

Recognizing some of the limits, a second study was planned and implementation of it began. The hope was to have another set of data with which to explore the interaction between demographic indicators and student responses to the survey. The second study also would have provided another opportunity to view the group of students who responded that they do not like or enjoy clickers, furthering the findings of the first study.

Second Study: Linked Pre- and Post- Survey Results

Purpose. This study was designed and implementation began in the Spring of 2020. A pre-test was administered, but the intervention and post-test could not be completed due to the outbreak and effects of COVID-19. Therefore, I will report this study as a design for future implementation. The purpose of the second study is to fix the limitations in the design of the first study and build on the findings. Study two is still designed to be a preliminary study but should improve the ability to explore the relationship between students’ perception of clickers and the demographic groups they belong to. To do this, I propose to survey a second group of students in a large-enrollment upper-level college course. The class will need to use clickers in a variety of ways, e.g. using methods from novel pedagogies and tools for enhancing the classroom.

Students will be surveyed at the beginning and end of the semester to gauge changes in perception. Demographic data will be collected to see if there is any correlation between demographic factors and student perceptions. Items will include whether students are familiar with clickers before the class, allowing analysis of differences in perception between students first experiencing clickers and those who have used them before. A key feature of this study is linking individual student responses using randomly generated codes unique to each student. With random codes, anonymity is maintained in the analysis of the survey data, but students pre- and post-surveys can be linked.

Recruitment. Recruitment will occur similarly to the original pilot study. Students will be given an information letter outlining the study and have time to ask for clarification if needed. When students agree to participate, they will be given the code needed to complete the online survey. Students who turn in a survey will receive a cookie. The survey will be anonymous and will not contribute to or detract from their grade in the course.

Measures. The measures from the first study will be used. The only addition to the survey is a new question at the very beginning that asked for a code.

Administration. The instrument will be administered online. Qualtrics, an online polling platform, will be used to collect pre- and post-test data. Students will be given class time to complete the survey. Students can use personal devices (phones, computers, tablets, and the like) to complete these surveys. Students will enter the same code for both tests, linking the pre- and post-surveys. The reasons for moving to the online format are to simplify the data collection process and aid in data manipulation. In the first study, data entry was entered manually. This task was time-consuming and monotonous. It also added an unnecessary chance of error to the study because of the fallible input method. Qualtrics can export in the needed digital format, streamlining the process. This change will also decrease the possibility of human error when inputting data. The online format may bring new technological issues, such as students being unable to complete the survey because of internet errors or compatibility issues, but the benefits of the technology should outweigh possible inconveniences.

Analysis. The analysis will be run similarly to the first study. The addition is the link between pre- and post- surveys. This link will solve the limitations of the first study by allowing me to view change in student perception over the semester, rather than viewing a single point in time. This design allows for better control of the group as it provides a baseline to work against, allowing reduced error in the assumptions made from the data. Since there will be two data points, a repeated-measures ANOVA will be used instead of one-way ANOVA, such as the ones performed in the first study. In this study, the same participant will be observed at multiple time points and those observations are related. This approach provides a more precise estimate of experimental error using this data compared to a simple one-way ANOVA (Shavelson, 1997). Using ANOVAs, I can again compare the differences between the way the different demographic groups responded to the questions. I would also still be able to look for trends in the means and examine the group of students who respond that they do not like clickers. This design is still pre-experimental and lacks foundational features of an experimental study, such as an external control group. There are many ways to further improve the first study. I considered including open-ended questions, interviews, and an external control group. The study could also benefit from a better instrument that had more types of questions and different ways of asking the same questions to establish reliability. The analysis could benefit from more complex and complete analysis methods. Changes of this magnitude, however, would have been beyond the scope of a master's thesis. I would like, in the future, to have the opportunity to implement these strategies.

CHAPTER 4
CONCLUSION

To refresh, this project was started by asking the simple question: What do clickers do for students? To answer this question a two-part method was employed. First, conducting a review of the literature answered specific questions, which include: What are the current uses of clickers and what impact do they have on students? What are the best practices and how should they be implemented? Findings from the literature not only answered these questions but highlighted gaps in our knowledge that I thought were worth investigating with a preliminary survey study. The focus of the survey study was to examine whether different kinds of students have different impressions of clickers. Both parts contributed valuable knowledge that especially takes shape when viewed as a whole. My conclusion to my initial question is that students can be affected differently based on the experience they have with clickers. Most importantly, the experience is shaped by the type of classroom. The second question, created in response to the literature review is "Given that science classrooms include a diverse set of students (e.g. students from different races, ethnicities, genders, and worldviews), how do these groups experience clickers differently?" While not definitively answering the original research question, the pilot study helped to shape my view of what kind of studies should be done about clickers and provided preliminary information about the connection between demographic groups and clicker perception.

A final finding arose tangential to the question about what clickers can do for students. In researching and thinking about technology and education, I conclude that technology itself is not a "drag and drop" solution to achieve active teaching in a classroom. A stark contrast can be seen between classrooms that use quality pedagogy and technology versus those that only use technology. This observation sparked reflection as to what technology does in a classroom. I believe that technology improves the efficiency or capability of pedagogical techniques. I did find instances where it can hamper learning, such as the technology issues when first using clickers, but, when technology is working well, it supports the classroom in ways that could not occur without it. Ideas about how humans learn have seemed to take a cyclical journey, but, with modern improvements, our capability to use quality teaching strategies has been increased. Considering all this, I advocate the use of clickers in classrooms with the condition that they are used in a classroom that uses novel pedagogy paired with clickers.

Conclusions from Scholarship on Clickers

The review of clicker literature provided a base for my understanding. Through the pieces I read, I was able to draw some conclusions about the current environment of clickers being used in the classrooms and about clicker use generally. A first realization is that students have the same questions that I did going into this work. As students are required to buy these devices, they have opinions about what they are used for. This led me to really think about why instructors adopt clickers. What outcomes are sought? This will vary from instructor to instructor, but it seems there are some general criteria when introducing clickers into a classroom. In my reading, the theoretical model TPACK explained what I was finding. The relationship of successfully using clickers, how to achieve the most good, is reliant on pedagogy and the technology. This was especially evident in the matrix I created which highlights the outcomes of adopting clickers with and without novel pedagogies. A final conclusion relates to equity in clicker use. I was interested in work that showed clickers impact students differently. If clickers do impact students in different ways, they should be identified, measured, and then a conversation needs to happen about the implications of those differences. There is not enough work to make those conclusions and there is room for more research.

My first realization about students having questions was solidified by students expressing concern over clickers adding extra costs to courses combined with their vocal dislike for certain clicker practices. Many of the practices that students named seemed to center around the sole benefit of the teacher (Kay & LeSage, 2009). If instructors are going to require clickers for their class, adding financial costs to students, the use of clickers should focus on helping the students. As students are required to spend an increasing amount for school, instructors need to be sure of the reason they use clickers. If it is solely for the benefit of the instructor or to fulfill a requirement for interactivity, should students be required to pay for it? In the history of clickers, when they were just a tool to increase efficiency in classroom activities as a replacement for other modes of response, the money for their installation was furnished by the university. The hardwired systems of times past had to be installed into the classrooms and lecture halls and were used for multiple classes by multiple students. As technology progressed, the classroom went wireless and students now buy one device and a subscription, taking it to classes that use the clicker. While the utility and value increase as more instructors use clickers, students are still the ones paying the bill. If they are going to be required to buy these devices for their educational career, shouldn’t the devices be used in a way that benefits them and their learning? Is it fair to require students to purchase devices if they are not receiving all the possible benefits or any at all? To better understand the benefits I am discussing, it is useful to think about the differences between the classrooms that have clickers for logistical reasons and the ones that engage students with novel pedagogy assisted by clickers.

From the literature review and applicable history, I can see that, while clickers are sometimes implemented into traditional classrooms to seemingly check a box for active learning, there is serious good that they can accomplish. When clickers are paired with a pedagogy that maximizes their capabilities as learning tools, like those provided, students and instructors can experience benefits. Interestingly though, when looking outside of logistical benefits, I can see similar benefits in learning and benefits to students when clickers are not present, but the pedagogies still are present. The pedagogies themselves rely heavily on discussion, students working with one another to achieve common knowledge. This approach to teaching echoes the earliest methods of formal learning. Even though new technologies abound, basic human nature and ways of learning may not change. The idea about what technology does for a classroom, especially clickers, became muddy for me when I read the literature that showed comparable learning gains by using some other response method (whiteboards, flashcards, or paper) rather than clickers in the highlighted pedagogies. From these findings, I concluded that pedagogy was the main contributor to student success. If this is the case, why should students be required to buy clickers when there are cheaper, more available options? The answer that I arrived at is that technology can improve on the good things found within the pedagogy or teaching method. While flashcards can still allow students to respond, clickers take away the need to count how many students responded. They decrease the time spent on the polling activity. They streamline interactions. They also open options such as anonymity, game show-style interaction, and communication with the instructor. Bringing in technology to the classroom can also engage students because it is part of their daily life. It utilizes what students already have experience with. Hence, a conclusion is that just using clickers in a classroom does not affect learning gains, but the method of using clickers does. So, what do clickers provide? Clickers provide the ability to efficiently collect, display, and grade the responses of students. This is not found in classrooms without clickers. It seems one benefit is the functionality of clickers. This echoes the thought that led to the creation of the outcomes chart (Figure 2) that succinctly shows the comparison and illustrates these benefits with appropriate citations. Clickers in and of themselves are not a magical tool, but when used effectively, clickers can be valuable teaching tools benefiting both the teacher and student. For clickers to be a contributing tool in the classroom, rather than an “insipid contrivance” (Judson & Sawada, 2006), certain conditions must be met.

My ideas about this combination of pedagogy and technology are not new. TPACK is a general theoretical model that focuses on the different aspects needed to have a successful learning environment that incorporates technology. It is important to note that TPACK is not specifically about clickers but does compliment my findings. TPACK presents three knowledge areas an instructor must be familiar with: content, technology, and pedagogy (Graham, 2011). Recent work published in *Pedagogical Content Knowledge for Educators* highlights the benefits of the technology used in a TPACK classroom (Graham et al., 2009). The benefits are speeding up data collection during class, seeing things that could not be otherwise seen, and saving time. Following TPACK enhances teacher confidence in both the technology and their ability to better their instruction with the technology (Graham et al., 2009). Any lack of the three parts will result in decreased fluency in the classroom as it affects the complex relationships and interaction of the connected areas (Archambault & Barnett, 2010). Keeping this in mind, instructors should be competent in all areas of TPACK (content, technology, and pedagogy) and trained sufficiently to create the TPACK environment, any shortcomings will be reflected in the poorer learning and performance of students.

Applied to clickers, TPACK suggests that issues with technology can inhibit the efficiency of pedagogy and content; lack of technical competency has been identified as a hindrance to achieving the potential benefits of clickers. In the review, teachers were aware of student concerns and uncomfortable with clickers. Focusing on developing teacher ability and familiarity with clickers would strengthen the likelihood of positive learning outcomes according to the TPACK model. Pedagogy was a large part of my findings; pairing clickers with a quality pedagogy increases benefits. The TPACK model echoes this also. Moving forward, TPACK can be a guide for how to incorporate clickers and alleviate some of the identified drawbacks. With adequate training in technology and pedagogy, instructors can provide students with quality learning spaces and help them to succeed.

A final trend that I wish to conclude with centers around equity in clicker use. Much of the perception data I found was limited, as most of the work did not include indicators or discussions about the students who were participating. It focused more broadly on the student body simply praising or disliking clickers. The issue is that I consistently saw that there was a group of students who did not care for clickers, also noted by Caldwell (2007). There was a lack of information about who was in that group. I thought it was a disservice to the students in that group to not further explore who they were. There was some literature I found that has begun to explore the notion that clickers may impact students differently, specifically students from different demographic groups. Combining these two ideas, I think it is prudent to explore further the students who do not feel like clickers are for them. As higher education strives for equity in education, it is not enough to accept that some students will not like classroom practices and techniques, but it behooves us to ask why. How can lack of engagement due to cultural differences be addressed? If there is a measurable difference between how genders perform, what are the implications? This topic inspired my original study, which provided more information on this topic and provided me more evidence that this is an important topic.

Conclusions from Student Survey

The learning from my study was not only about the students' perceptions, although that was part of it, but also included better understanding data, the experimentation process, and how messy 'real-life' data can be. To frame these different aspects of learning and the related conclusions, I will briefly touch on my learning, focusing on my experiences with the study. I will then discuss the contributions that the study itself makes and the conclusions I made from the data. In this section, I will pay especial attention to the results in terms of equity and how it relates to the 'bigger picture'.

In conducting the first study, I was able to learn more about experimental design. I also learned how valuable this work can be for students. When students were asked to participate, many of them were glad that someone cared about their feelings related to the tools that they used in class. Memorably, one student even expressed a desire to do similar work. Admittedly, when the first study did not end as planned, it was difficult to overcome feelings of failure. With the help of my committee, I realized that a lot of research goes wrong and that it only matters about how you go forward.

While the second study was cut short due to the unexpected circumstances of COVID-19, it stands as an example of a study that begins to explore an important question that should be asked when implementing anything into the classroom, how are the vast variety of students in classrooms being impacted? From the pilot study, I can contribute another piece to the literature and the general desire to see what clickers do for students. My findings from the ANOVA analysis, as a simple exit study, show no difference in student perception between males and females, contrary to prior work in the field. This does not negate the past work or the need to perform this kind of study, but rather suggests further exploration through larger sample sizes. The same can be said for each of the demographic indicators: race, age, prior clicker experience, and first-generation college student status.

When thinking about the data outside of my ANOVA results, some trends are visible. Females responded more positively to clickers than males did. White students had lower mean impressions than the other race/ethnicity groups. White males had the lowest mean response when compared to all other groups. Similar trends are evident for the group of students who did not like clickers. The percentage of males in that group was twice that of females. The percentage of white students in this group was greater than the other races/ethnicities, except for the "Prefer Not to Answer" group. These two pieces of information, although not definitive, agree with prior findings about male students and their perception of clickers (Hoekstra, 2009). Adding that white students had lower mean perception scores and were, by percentage, more often in the group that disliked clickers raises some important questions to address. Although these students may not like clickers, is it hurting their performance in the class? Is it okay to use a technology that benefits minorities more? If there was no ill-effect on white or male students, other than perception, I would argue that clickers are equitable. If using them can increase participation, enjoyment, and learning gains for students from minority groups, of course it is a good thing. But if they negatively impact performance of other students, it is a different conversation to have. Centered on this idea, more research to explore the connections between performance and clickers will need to be accomplished. There will also need to be more research performed about students' perceptions and the whys of their answers, to better illustrate and find differences. Simply put, a comprehensive look at how each of the different uses of clickers affects students is needed. The field of research is vast in terms of classes that are viewed, techniques that are used, and the results of the studies. My research has solidified my opinion that some baseline is needed to compare against since there are so many differences between the classes being compared in the many clicker studies. This baseline will allow us to get at the deep questions about differential impact.

A final point that came up during the writing of this thesis came during a seminar listening to the work of Dr. Katelyn Cooper. Her work deals with looking at the anxiety of undergraduates in active learning environments. This led me to read some of the current literature in this niche of active learning research. A general finding is that students may not care to interact with their fellow students or their instructor in some settings (Cooper et al., 2018; Henning et al., 2019). This could be problematic since

69.6% of the students said clickers increased participation with the instructor and 82.3% said that clickers increased participation with their classmates. A limit of my study is that I did not ask if they liked the increased interaction with the instructor and/or fellow classmates. The idea that some students, while agreeing clickers increased interaction, dislike the new interaction raises cause for consideration and concern. It further deepens those contributing factors to student identity that need consideration when looking at implementing clickers.

Reflection

Thinking about all the information covered in this thesis, facts, numbers, and conclusions can overwhelm how this all ties into a greater picture that spans outside of clickers. In this last section, I want to do just that. Studying clickers has not only inspired me to be more thoughtful about classroom practices and technologies but has made me think about what one clicker is compared to the vast heap we call the world. Much of what I have discussed is not groundbreaking or even new. Discussing that we should think about all students in the classroom and their overlapping, interacting identities is not new. Discussing that technology is only useful when someone is familiar with it is common sense. Discussion and argumentation as teaching tools have been around since “the land before time.” Clickers are being paired with knowledge that has existed long before a clicker was ever invented. So, what really is the point or purpose of clickers and where do they fit into the “grander scheme”? In my personal reflection, I centered on the idea of discussion being a driving force in clicker success and the history of discussion in learning.

Education has taken many forms over the years, different models that instructors follow meant to teach students. Some methods have withstood the test of time and are present just as they were at their introduction, possibly hundreds of years ago. In the words of Dr. Francesco Cordasco, “Everything we do in the classroom today represents a surviving vestige of some great (or near great) innovation […]” (Cordasco, 1976, p. xi) Considering this, by highlighting certain developments in education we can see that successful methods supersede boundaries of time and place. The idea of discussion, using reasoned arguments, and this idea of discussing truth were staples of education in times long since passed. The Socratic method is an idea still in use today from these early thinkers, where discussions stimulate learning and engage students with ideas and the shortcoming of their understanding. If people learned in antiquity through discussion and community discourse, it may seem odd that we are now “finding” that discussion is the feature in modern pedagogy that helps learners. I wondered where the didactic method of teaching came from and why it is popular in today’s higher education institutions (Knight & Wood, 2005).

Specifically looking at American universities, the “modern education system” at least for higher education in America finds roots in the European universities of the 1700 and 1800s. Aside from the structure, another surviving commonality is that of the didactic teaching method. The didactic method is modeled in a fashion where a more knowledgeable instructor imparts wisdom on those coming to learn. The grand lecture halls and uniformity where students sit and listen is the key feature that became prevalent as universities became more set or standardized (Cordasco, 1976). This was the way to teach; students come in, sit down, and write.

Changes in learning theory have occurred thanks to people like John Dewey challenging more traditional didactic methods of teaching (Cordasco, 1976). Dewey stated that instructors must “Teach students, not subjects” (As cited in Cordasco, 1976, p. 139). We see a desire to focus on the students’ learning, rather than orate. It is important to note, returning to the idea that all good things we do in the classroom today are echoes of past innovations, proponents of a different instruction model have been present in the discussion from very early years. Notably, Friedrich Froebel (1782-1852) who argued that education should embody things like social interaction, self-activity, encouraging creativity, and movement (Cordasco, 1976). We can see these very practices still being discussed and argued today if one looks through an educational research journal. We see a continual push to try and move away from didactic lectures, especially as disadvantages are identified and proven.

A lecture is a passive form of instruction. Simply put, traditional classrooms are not as effective at stimulating higher thinking skills, information is forgotten, students’ attention decreases, and the number of students’ notes decreases (Bonwell, 1996; DiCarlo, 2009; DiPiro, 2009; S. Freeman et al., 2014; Miller et al., 2013). I have found in my readings and study that people have not changed a lot over the centuries in terms of learning. Beneficial, quality, good teaching methods were being discussed many years ago by those in antiquity and those closer to our time. This notion, for me, was solidified by studying the “Eight-year Study.” At the time of John Dewey who pushed for a more progressive type of education, opposition arose propounding that these ideas were “anti-educational” (Pinar & Bullough, 2010). A study was conducted from 1930 until 1938, examining the performance of students instructed under “old” methods and students instructed using “progressive” instruction. Generally, the study highlighted the superiority of the “new” methods. While culture, technology, knowledge, and other facets of life change, it seems that the methods that have worked, like discussion and open discourse in antiquity, continue to work today. While they are being presented as new ideas, “we come to mature realization that every idea […] which is heralded as new is not new at all” (As cited in Cordasco, 1976, p. xi). While ideas about learning may not be completely new, the technology that we use in classrooms can be. We then must consider what role technology plays in learning. Expanding, what role do clickers play in this back and forth search for the “better teaching method?”

Clickers have the potential to be a good learning tool and addition to classrooms, especially those large-enrollment classrooms where students may otherwise not have a chance to participate. The caveat is that the benefits of clickers are greatly dependent on their use. Instructors should be considerate of this reality when deciding to use clickers, especially when students are required to purchase them. The practices can shape students' perceptions of the devices for better or worse. More importantly, when used well by instructors, the benefits can enhance and improve the student experience. There is a diverse body of students in classrooms across the US and the globe. We need to account for them when implementing learning and teaching techniques. To truly work toward an inclusive educational experience, we need to account for the differences between students to achieve equity. There is a lot of work to do in trying to understand the impact of clickers, but it is an important, fruitful work that, as it continues, can prove beneficial to the modern classroom.

REFERENCES

Abrahamson, L. (2006). A Brief History of Networked Classrooms: Effects, Cases, Pedagogy, and Implications. In D. A. Banks, *Audience Response Systems in Higher Education: Applications and Cases* (pp. 1–25). Information Science Publishing.

Archambault, L. M., & Barnett, J. H. (2010). Revisiting technological pedagogical content knowledge: Exploring the TPACK framework. *Computers & Education*, *55*(4), 1656–1662. https://doi.org/10.1016/j.compedu.2010.07.009

Aljaloud, A., Gromik, N., Billingsley, W., & Kwan, P. (2015). Research trends in student response systems: A literature review. *International Journal of Learning Technology*, 10(4), 313. https://doi.org/10.1504/IJLT.2015.074073

Anderson, Nick. (2018, October 15). *Harvard admissions trial opens with university accused of bias against Asian Americans* [News]. Washington Post. https://www.washingtonpost.com/education/2018/10/15/harvard-admissions-goes-trial-university-faces-claim-bias-against-asian-americans/

Arizona State University. (2018). *Clickers @ ASU*. University Technology Office. https://uto.asu.edu/services/tools/clickers

Aronson, J., Quinn, D. M., & Spencer, S. J. (1998). Stereotype Threat and the Academic Underperformance of Minorities and Women. In J. K. Swim & C. Stangor (Eds.), Prejudice (pp. 83–103). Academic Press. https://doi.org/10.1016/B978-012679130-3/50039-9

ASU Charter. (2019). Retrieved July 03, 2020, from https://president.asu.edu/asu-mission-goals

Baer, J. (2015, February 18). *How are clickers being used on campus? And who is using them?*. Technology for Teaching and Learning [Worcester Polytechnic Institute]. Technology for Teaching and Learning: Academic Technology Center at WPI. https://wp.wpi.edu/atc-ttl/2015/02/18/how-are-clickers-being-used-on-campus-and-who-is-using-them/

Banfield, J., & Wilkerson, B. (2014). Increasing Student Intrinsic Motivation And Self-Efficacy Through Gamification Pedagogy. *Contemporary Issues in Education Research* (Online); Littleton, 7(4), 291. http://dx.doi.org.ezproxy1.lib.asu.edu/10.19030/cier.v7i4.8843

Bapst, J. J. (1971). *The Effect of Systematic Student Response Upon Teaching Behavior*. University of Washington.

Barnes, M. E., & Brownell, S. E. (2017). A Call to Use Cultural Competence When Teaching Evolution to Religious College Students: Introducing Religious Cultural Competence in Evolution Education (ReCCEE). *CBE—Life Sciences Education*, 16(4), es4. https://doi.org/10.1187/cbe.17-04-0062

Barnes, M. E., Truong, J. M., & Brownell, S. E. (2017). Experiences of Judeo-Christian Students in Undergraduate Biology. *CBE—Life Sciences Education*, 16(1), ar15. https://doi.org/10.1187/cbe.16-04-0153

Barrio, C. M., Muñoz-Organero, M., & Soriano, J. S. (2016). Can Gamification Improve the Benefits of Student Response Systems in Learning? An Experimental Study. *IEEE Transactions on Emerging Topics in Computing*, 4(3), 429–438. https://doi.org/10.1109/TETC.2015.2497459

Basquiat [@JerryNotGerry]. (2018, April 16). *My man has 9 clickers lined up and ready. If you can't hold down your squad like this, you're useless*😆😆 [Tweet; Image]. Retrieved February 19, 2019, from @JerryNotGerry website: https://twitter.com/JerryNotGerry/status/986040921212051456

Beatty, I. D., Gerace, W. J., Leonard, W. J., & Dufresne, R. J. (2006). Designing effective questions for classroom response system teaching. American Journal of Physics, 74(1), 31–39. https://doi.org/10.1119/1.2121753

Beekes, W. (2006). The 'Millionaire' method for encouraging participation. *Active Learning in Higher Education*, 7(1), 25–36. https://doi.org/10.1177/1469787406061143

Berkey, N. (2018, November 19). *Top Hat Ranked Number 200 Fastest Growing Company in North America on Deloitte's 2018 Technology Fast 500TM*. Top Hat. https://tophat.com/press-releases/top-hat-ranked-number-200-fastest-growing-company-in-north-america-on-deloittes-2018-technology-fast-500/

Bessler, W. C. (1969). *The Effectiveness of an Electronic Student Response System in Teaching Biology to the Non-Major Utilizing Nine Group-Paced, Linear Programs*. Ball State University, Munice, Indiana.

Bessler, W. C., & Nisbet, J. J. (1971). The Use of an Electronic Response System in Teaching Biology. Science Education, 3, 275–284. Retrieved from Gumberg Library. Black, P., & Wiliam, D. (1998). *Assessment and classroom learning. Education*, 5(1), 71–73.

Bonwell, C. C. (1996). Enhancing the lecture: Revitalizing a traditional format. *New Directions for Teaching and Learning*, 1996(67), 31–44. https://doi.org/10.1002/tl.37219966706

Bostock, S.J., J.A. Hulme, and M.A. Davys. (2006). CommuniCubes: Intermediate technology for interaction with student groups. In D.A. Banks (Ed.), *Audience response systems in higher education* (pp. 321-333). Hershey, PA: Information Science Publishing.

Bransford, J., Brown, A. L., & Cocking, R., & National Research Council (U.S.) (Eds.). (2000). *How people learn: Brain, mind, experience, and school* (Expanded ed). National Academy Press.

Brost, B. D., & Bradley, K. A. (2006). Student Compliance with Assigned Reading: A Case Study. *Journal of Scholarship of Teaching and Learning*, *6*(2), 101–111.

Brown, J. D. (1972). An Evaluation of the Spitz Student Response System in Teaching a Course in Logical and Mathematical Concepts. *The Journal of Experimental Education*, 40(3), 12–20.

Bruff, D. (2009). *Teaching with Classroom Response Systems: Creating active learning environments*. John Wiley & Sons.

Bruff, D. (2010, June 11). *Classroom Response Systems ("Clickers")*. Center for Teaching. https://wp0.vanderbilt.edu/cft/guides-sub-pages/clickers/

Buil, I., Catalán, S., & Martínez, E. (2019). The influence of flow on learning outcomes: An empirical study on the use of clickers. *British Journal of Educational Technology*, 50(1), 428–439. https://doi.org/10.1111/bjet.12561

Bunce, D. M., Flens, E. A., & Neiles, K. Y. (2010). How Long Can Students Pay Attention in Class? A Study of Student Attention Decline Using Clickers. *Journal of Chemical Education, 87(12),* 1438–1443. https://doi.org/10.1021/ed100409p

Burnstein, R. A., & Lederman, L. M. (2001). Using wireless keypads in lecture classes. *The Physics Teacher,* 39(1), 8–11. https://doi.org/10.1119/1.1343420

Byrd, G. G., Coleman, S., & Werneth, C. (2004). Exploring the Universe Together: Cooperative Quizzes with and without a Classroom Performance System in Astronomy 101. *Astronomy Education Review*, 3(1), 26–30.

Canning, E. A., Muenks, K., Green, D. J., & Murphy, M. C. (2019). STEM faculty who believe ability is fixed have larger racial achievement gaps and inspire less student motivation in their classes. *Science Advances*, 5(2). https://doi.org/DOI: 10.1126/sciadv.aau4734

Caldwell, J. E. (2007). Clickers in the Large Classroom: Current Research and Best-Practice Tips. *CBE— Life Sciences Education,* 6(1), 9–20. https://doi.org/10.1187/cbe.06-12-0205

Carnaghan, C., & Webb, A. (2007). Investigating the Effects of Group Response Systems on Student Satisfaction, Learning, and Engagement in Accounting Education. *Issues in Accounting Education*; Sarasota, 22(3), 391–409.

Cardinal, R. N., & Aitken, M. R. F. (2006). *ANOVA for the Behavioural Sciences Researcher*. L. Erlbaum.

Casanova, J. (1971). An instructional experiment in organic chemistry. The use of a student response system. *Journal of Chemical Education*, 48(7), 453. https://doi.org/10.1021/ed048p453

Castillo-Manzano, J. I., Castro-Nuño, M., López-Valpuesta, L., Sanz-Díaz, M. T., & Yñiguez, R. (2016). Measuring the effect of ARS on academic performance: A global meta-analysis. *Computers & Education*, 96, 109–121. https://doi.org/10.1016/j.compedu.2016.02.007

Chambers, E. L. & Henderson J. B. (2020). *The Past, Present, and Future of Clickers: A Critical Review.* Manuscript submitted for publication.

Cheesman, E., Winograd, G., & Wehrman, J. (2010). Clickers in Teacher Education: Student Perceptions by Age and Gender. *Journal of Technology and Teacher Education*, 18(1), 35–55.

Chu, Y. (1972). *Study and Evaluation of the Student Response System in Undergraduate Instruction at Skidmore College*. Report to the National Science Foundation. Education Support Project of the General Electric Company, 21.

Coleman, M. J., & Ganong, L. H. (2014). *The Social History of the American Family: An Encyclopedia*. SAGE Publications.

Cooper, K. M., Downing, V. R., & Brownell, S. E. (2018). The influence of active learning practices on student anxiety in large-enrollment college science classrooms. *International Journal of STEM Education*, 5(1), 23. https://doi.org/10.1186/s40594-018-0123-6

Cooper, M. M. (1995). Cooperative Learning: An Approach for Large Enrollment Courses. *Journal of Chemical Education*, 72(2), 162. https://doi.org/10.1021/ed072p162

Cordasco, F. (1976). *A Brief History of Education: A handbook of information on greek, roman, medieval, renaissance, and modern educational practice*. Rowman & Littlefield.

Cortright, R. N., Collins, H. L., Rodenbaugh, D. W., & DiCarlo, S. E. (2003). Student retention of course content is improved by collaborative-group testing. *Advances in Physiology Education*, 27(3), 102–108. https://doi.org/10.1152/advan.00041.2002

Crossgrove, K., & Curran, K. L. (2008). Using Clickers in Nonmajors- and Majors-Level Biology Courses: Student Opinion, Learning, and Long-Term Retention of Course Material. *CBE Life Sciences Education*, 7(1), 146–154. https://doi.org/10.1187/cbe.07-08-0060

Crouch, C. H., & Mazur, E. (2001). Peer Instruction: Ten years of experience and results. *American Journal of Physics*, 69(9), 970–977. https://doi.org/10.1119/1.1374249

Csikszentmihalyi, Mihaly. (1975). *Beyond Boredom and Anxiety* (1st ed.). San Francisco: Jossey-Bass Publishers.

Cumming, G. (2013). Cohen's d needs to be readily interpretable: Comment on Shieh (2013). *Behavior Research Methods*, 45(4), 968–971. https://doi.org/10.3758/s13428-013-0392-4

CWSEI. (2019). *Clicker Resources*. Carl Wieman Science Education Initiative at the University of British Columbia. http://www.cwsei.ubc.ca/resources/clickers.htm

d'Inverno, R., Davis, H., & White, S. (2003). Using a personal response system for promoting student interaction. *Teaching Mathematics and Its Applications: An International Journal of the IMA*, 22(4), 163–169. https://doi.org/10.1093/teamat/22.4.163

DiCarlo, S. E. (2009). Too much content, not enough thinking, and too little FUN! *Advances in Physiology Education*, 33(4), 257–264. https://doi.org/10.1152/advan.00075.2009

Dijk, L. A. V., Berg, G. C. V. D., & Keulen, H. V. (2001). Interactive lectures in engineering education. *European Journal of Engineering Education*, 26(1), 15–28. https://doi.org/10.1080/03043790123124

DiPiro, J. T. (2009). Why Do We Still Lecture? *American Journal of Pharmaceutical Education*, 73(8), 137. https://doi.org/10.5688/aj7308137

Donovan, B. M., Semmens, R., Keck, P., Brimhall, E., Busch, K. C., Weindling, M., … Salazar, B. (2019). Toward a more humane genetics education: Learning about the social and quantitative complexities of human genetic variation research could reduce racial bias in adolescent and adult populations. *Science Education*, 103(3), 529–560. https://doi.org/10.1002/sce.21506

Draper, S. W., & Brown, M. I. (2004). Increasing interactivity in lectures using an electronic voting system: Interactivity in lectures using electronic voting system. *Journal of Computer Assisted Learning*, 20(2), 81–94. https://doi.org/10.1111/j.1365-2729.2004.00074.x

Duncan, D. K., Hoekstra, A. R., & Wilcox, B. R. (2012). Digital Devices, Distraction, and Student Performance: Does In-Class Cell Phone Use Reduce Learning? *Astronomy Education Review, 11*(1). https://doi.org/10.3847/AER2012011

Dworetzky, J. P. (1976). Audience response system (Patent No. US3943641A).

Eddy, S. L., Brownell, S. E., & Wenderoth, M. P. (2014). Gender Gaps in Achievement and Participation in Multiple Introductory Biology Classrooms. *CBE—Life Sciences Education*, 13(3), 478–492. https://doi.org/10.1187/cbe.13-10-0204

El-Rady, J. (2006). To Click or Not to Click: That's the Question. *Innovate: Journal of Online Education*, 2(4). https://www.learntechlib.org/p/104268/

Fagen, A. P., Crouch, C. H., & Mazur, E. (2002). Peer Instruction: Results from a Range of Classrooms. *The Physics Teacher*, 40(4), 206–209. https://doi.org/10.1119/1.1474140

Feise, R. J. (2002). Do multiple outcome measures require p-value adjustment? *BMC Medical Research Methodology*, *2*(1), 8. https://doi.org/10.1186/1471-2288-2-8

Fies, C., & Marshall, J. (2006). Classroom Response Systems: A Review of the Literature. *Journal of Science Education and Technology*, *15*(1), 101–109. https://doi.org/10.1007/s10956-006-0360-1

Forbes, J. D. (2009). *You will do better if I watch: Anonymity, identifiability and audience effects in a stereotype threat situation.* [Thesis]. https://researchspace.ukzn.ac.za/handle/10413/535

Freeman, M., & Blayney, P. (2005). Promoting interactive in-class learning environments: A comparison of an electronic response system with a traditional alternative. *Proceedings of the Eleventh Australasian Teaching Economics Conference: Innovation for Students Engaged in Economics*, 23–34. University of Sydney.

Freeman, M., Blayney, P., & Ginns, P. (2006). Anonymity and in-class learning: The case for electronic response systems. Australasian Journal of Educational Technology, 22(4). https://doi.org/10.14742/ajet.1286

Freeman, M., Bell, A., Comerton-Forde, C., Pickering, J., & Blayney, P. (2007). Factors affecting educational innovation with in-class electronic response systems. *Australasian Journal of Educational Technology*, 23(2). Retrieved from http://ascilite.org.au/ajet/submission/index.php/AJET/article/view/1262

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, 111(23), 8410–8415. https://doi.org/10.1073/pnas.1319030111

Friedman, I. C. (2004). *Education reform*. Facts On File.

Froehlich, H. P. (1963). What about Classroom Communicators? *Audio Visual Communication Review*, 11(3), 19–26. JSTOR.

Garg, D. P. (1975, June). Experiments with a Computerized Response System: A favorable experience. *Conference on Computers in the Undergraduate Curricula*, Fort Worth, Texas.

Gavassa, S., Benabentos, R., Kravec, M., Collins, T., & Eddy, S. (2019). Closing the Achievement Gap in a Large Introductory Course by Balancing Reduced In-Person Contact with Increased Course Structure. *CBE—Life Sciences Education*, 18(1), ar8. https://doi.org/10.1187/cbe.18-08-0153

Gok, T. (2011). An Evaluation of Student Response Systems from the Viewpoint of Instructors and Students. *The Turkish Online Journal of Educational Technology*, 10(4), 17.

Gooblar, D. (2014, September 24). *They Haven't Done the Reading. Again.* ChronicleVitae. https://chroniclevitae.com/news/719-they-haven-t-done-the-reading-again

Goodwin, S., & Hoffman, C. (2006). *A Clicker for Your Thoughts: Technology for active learning*. New Library World, 107(9/10), 422–433. https://doi.org/10.1108/03074800610702606

Graham, C., Burgoyne, N., Cantrell, P., Smith, L., St. Clair, L., & Harris, R. (2009). TPACK Development in Science Teaching: Measuring the TPACK Confidence of Inservice Science Teachers. *TechTrends*, *53*(5), 70–79. https://doi.org/10.1007/s11528-009-0328-0

Graham, C. R. (2011). Theoretical considerations for understanding technological pedagogical content knowledge (TPACK). *Computers & Education*, *57*(3), 1953–1960. https://doi.org/10.1016/j.compedu.2011.04.010

Gurin, P., Nagda, B., Ratnesh A., & Lopez, G. E. (2004). Benefits of Diversity in Education for Democratic Citizenship. *Journal of Social Issues*, 60(1):17-34. https://doi.org/10.1111/j.0022-4537.2004.00097.x

Guse, D. M., & Zobitz, P. M. (2011). Validation of the audience response system. *British Journal of Educational Technology*, 42(6), 985–991. https://doi.org/10.1111/j.1467-8535.2010.01120.x

Hatch, J., Jensen, M., & Moore, R. (2005). Manna from Heaven or "Clickers" from Hell: Experiences with an Electronic Response System. *Journal of College Science Teaching*, 34(7), 36–42.

Heath, B. D. (2009). *The Effects of Clicker Feedback on Student Success* [M.S., Angelo State University]. ProQuest Dissertations Publishing.

Henning, J. A., Ballen, C. J., Molina, S. A., & Cotner, S. (2019). Hidden Identities Shape Student Perceptions of Active Learning Environments. *Frontiers in Education*, 4. https://doi.org/10.3389/feduc.2019.00129

History. (2018, September 17). Stanford Graduate School of Education. https://ed.stanford.edu/about/history

Hoekstra, A. R. (2009). *A Socio-Cultural Analysis of the Use of Clickers in Higher Education* (Publication No. 3387478) [Pd.D., University of Colorado at Boulder]. ProQuest Dissertations Publishing.

Horowitz, L. (2006). ARS Evolution: Reflections and Recommendations. In D. A. Banks, *Audience Response Systems in Higher Education: Applications and Cases* (pp. 1–25). Information Science Publishing.

Hu, J., Peter Bertok, Margaret Hamiliton, Graeme White, Anita Duff, & Quintin Cutts. (2006). Wireless Interactive Teaching by Usin Keypas-Based ARS. In David A. Banks, *Audience Response Systems in Higher Education: Applications and Cases*. Information Science Publishing.

Huberty, C. J., & Morris, J. D. (1989). Multivariate analysis versus multiple univariate analyses. *Psychological Bulletin*, *105*(2), 302–308. https://doi.org/10.1037/0033-2909.105.2.302

Jacobs, P. (2015). *Dartmouth Students Allegedly Used These "Clickers" To Cheat In A Sports- Ethics Class*. Retrieved February 19, 2019, from Business Insider website: https://www.businessinsider.com/dartmouth-students-used-clickers-to-fake-attendance-2015-1

James, M. C., & Willoughby, S. (2010). Listening to student conversations during clicker questions: What you have not heard might surprise you! *American Journal of Physics*, 79(1), 123–132. https://doi.org/10.1119/1.3488097

Jamieson, S. (2004). Likert scales: How to (ab)use them. *Medical Education*, 38(12), 1217–1218. https://doi.org/10.1111/j.1365-2929.2004.02012.x

Jensen, M., Moore, R., & Hatch, J. (2002). Cooperative Learning: Part I: Cooperative Quizzes. *The American Biology Teacher*, 64(1), 29–34. https://doi.org/10.2307/4451232

Johnstone, D. B. (2004). The economics and politics of cost sharing in higher education: Comparative perspectives. *Economics of Education Review*, 23(4), 403–410. https://doi.org/10.1016/j.econedurev.2003.09.004

Johnstone, D. B., & Marcucci, P. N. (2008). Worldwide Trends in Higher Education Finance: Cost-Sharing, Student Loans, and the Support of Academic Research. *UNESCO Forum on Higher Education, Research and Development*, 36.

Jones, M. G., Jones, B. D., Hardin, B., Chapman, L., Yarbrough, T., & Davis, M. (2000). The Impact of High-Stakes Testing on Teachers and Students in North Carolina. *Phi Delta Kappan*, *81*(3), 199–203.

Judson, E., & Sawada, D. (2002). Learning from past and present: Electronic response systems in college lecture halls. *Journal of Computers in Mathematics and Science Teaching*, 21(2), 167–182.

Judson, E., & Sawada, D. (2006). Audience Response Systems: Insipid Contrivances or Inspiring Tools? In D. A. Banks, *Audience Response Systems in Higher Education: Applications and Cases* (pp. 26–39). Information Science Publishing.

Kang, H., Lundeberg, M., Wolter, B., delMas, R., & Herreid, C. F. (2012). Gender differences in student performance in large lecture classrooms using personal response systems ('clickers') with narrative case studies. *Learning, Media and Technology*, 37(1), 53–76. https://doi.org/10.1080/17439884.2011.556123

Kay, R. H., & LeSage, A. (2009). Examining the benefits and challenges of using audience response systems: A review of the literature. *Computers & Education*, 53(3), 819–827. https://doi.org/10.1016/j.compedu.2009.05.001

Kay, R., & Knaack, L. (2009). Exploring the Use of Audience Response Systems in Secondary School Science Classrooms. *Journal of Science Education and Technology*, 18(5), 382–392. https://doi.org/10.1007/s10956-009-9153-7

Kelly, K. G. (2009). Student response systems (“clickers”) in the psychology classroom: A beginner’s guide: (527282009-001) [Data set]. https://doi.org/10.1037/e527282009-001

Kennedy, G.E., Cutts, Q., & Draper, S. W. (2006). Evaluating electronic voting systems in lectures: Two innovative methods. In D. A. Banks, *Audience Response Systems in Higher Education: Applications and Cases* (pp. 155–174). https://doi.org/10.4018/978-1-59140-947-2.ch011

Kennedy, Gregor E., & Cutts, Q. I. (2005). The association between students’ use of an electronic voting system and their learning outcomes. *Journal of Computer Assisted Learning*, 21(4), 260–268.

Kiefer, J. M. (2013). *The effect of electronic response systems: Relationship between perceptions and class performance, and difference by gender and academic ability* [Ph.D., Ball State University]. ProQuest Dissertations Publishing.

King, D. B., & Joshi, S. (2008). Gender Differences in the Use and Effectiveness of Personal Response Devices. *Journal of Science Education and Technology*, 17(6), 544–552. https://doi.org/10.1007/s10956-008-9121-7

Knight, J. K., & Wood, W. B. (2005). Teaching More by Lecturing Less. *Cell Biology Education*, 4(4), 298–310. https://doi.org/10.1187/05-06-0082

Lantz, M. E. (2010). The use of ‘Clickers’ in the classroom: Teaching innovation or merely an amusing novelty? *Computers in Human Behavior*, 26(4), 556–561. https://doi.org/10.1016/j.chb.2010.02.014

Lasry, N. (2008). Clickers or Flashcards: Is There Really a Difference? *The Physics Teacher*, 46 (242), https://doi.org/10.1119/1.2895678

Lasry, N., Mazur, E., & Watkins, J. (2008). Peer instruction: From Harvard to the two-year college. *American Journal of Physics*, 76(11), 1066–1069. https://doi.org/10.1119/1.2978182

Leal, T. (2015). *Using Cooperative Quizzes* [The University of Iowa]. Retrieved September 30, 2019, from Office of Teaching, Learning & Technology website: https://teach.its.uiowa.edu/using-cooperative-quizzes

Leslie, L. L., & Brinkman, P. T. (1987). Student Price Response in Higher Education. *The Journal of Higher Education*, 58(2), 181–204. https://doi.org/10.1080/00221546.1987.11778239

MacArthur, J. R., & Jones, L. L. (2008). A review of literature reports of clickers applicable to college chemistry classrooms. *Chem. Educ. Res. Pract.*, *9*(3), 187–195. https://doi.org/10.1039/B812407H

Mankowski, A. (2011). Do "Clickers" Improve Student Engagement and Learning in Secondary Schools? https://doi.org/10.15760/etd.144

Martin, M. T., Belikov, O. M., Hilton III, J., Wiley, D., & Fischer, L. (2017). Analysis of Student and Faculty Perceptions of Textbook Costs in Higher Education. *Open Praxis: International Council For Open And Distance Education*, 9(1), 79–91.

Martyn, M. (2007, April 26). *Clickers in the Classroom: An Active Learning Approach*. Retrieved May 28, 2019, from EduCausereview website: https://er.educause.edu/articles/2007/4/clickers-in-the-classroom-an-active-learning-approach

Mazur, Eric. (1997). *Peer Instruction: A user's manual*. Prentice Hall.

Metcalf, H. (2005). Paying for University: The Impact of Increasing Costs on Student Employment, Debt and Satisfaction. *National Institute Economic Review*, 191(1), 106–117. https://doi.org/10.1177/0027950105052662

Miller, C. J., McNear, J., & Metz, M. J. (2013). A comparison of traditional and engaging lecture methods in a large, professional-level course. *Advances in Physiology Education*, 37(4), 347–355. https://doi.org/10.1152/advan.00050.2013

Morling, B., McAuliffe, M., Cohen, L., & DiLorenzo, T. M. (2008). Efficacy of personal response systems ("clickers") in large, introductory psychology classes. *Teaching of Psychology*, 35(1), 45–50. https://doi.org/10.1080/00986280701818516

National Science Education Standards. (1996). National Academy Press, 2101 Constitution Avenue, N.

Nicol, D. J., & Boyle, J. T. (2003). Peer Instruction versus Class-wide Discussion in Large Classes: A comparison of two interaction methods in the wired classroom. *Studies in Higher Education*, 28(4), 457–473. https://doi.org/10.1080/0307507032000122297

Nielsen, K. L., Hansen, G., & Stav, J. B. (2013). Teaching with student response systems (SRS): Teacher-centric aspects that can negatively affect students' experience of using SRS. *Research in Learning Technology*, 21. https://doi.org/10.3402/rlt.v21i0.18989

Nonacs, P. (2013, April 15). Why I Let My Students Cheat On Their Exam. Retrieved October 1, 2019, from Zócalo Public Square website: https://www.zocalopublicsquare.org/2013/04/15/why-i-let-my-students-cheat-on-the-final/ideas/nexus/

Norman, G. (2010). Likert scales, levels of measurement and the "laws" of statistics. *Advances in Health Sciences Education*, 15(5), 625–632. https://doi.org/10.1007/s10459-010-9222-y

Paschal, C. B. (2002). Formative assessment in physiology teaching using a wireless classroom communication system. *Advances in Physiology Education*, 26(1–4), 299–308. https://doi.org/10.1152/advan.00030.2002

Pelton, L.F. and T. Pelton. (2006). Selected and constructed response systems in mathematics classrooms. In D.A. Banks (Ed.), *Audience response systems in higher education* (pp. 175-186). Hershey, PA: Information Science Publishing.

Penuel, W. R., Boscardin, C. K., Masyn, K., & Crawford, V. M. (2007). Teaching with student response systems in elementary and secondary education settings: A survey study. *Educational Technology Research and Development*, 55(4), 315–346.

Pettit, R. K., McCoy, L., Kinney, M., & Schwartz, F. N. (2015). Student perceptions of gamified audience response system interactions in large group lectures and via lecture capture technology. *BMC Medical Education*, 15. https://doi.org/10.1186/s12909-015-0373-7

Pinar, W. F., & Bullough, R. V. (2010). *The Eight-Year Study*. Curriculum Inquiry, 40(2), 295–316. JSTOR.

Preszler, R. W., Dawe, A., Shuster, C. B., & Shuster, M. (2007). Assessment of the Effects of Student Response Systems on Student Learning and Attitudes over a Broad Range of Biology Courses. *CBE—Life Sciences Education*, 6(1), 29–41. https://doi.org/10.1187/cbe.06-09-0190

Pricing. (2020). iClicker. Retrieved May 14, 2020, from https://www.iclicker.com/pricing

Reay, N. W., Bao, L., Li, P., Warnakulasooriya, R., & Baugh, G. (2005). Toward the effective use of voting machines in physics lectures. *American Journal of Physics, 73*(6), 554–558. https://doi.org/10.1119/1.1862638

Roberts, H., & Diaz-Rainey, I. (2014). Educational Performance, Clicker Engagement and Ethnicity: Evidence from Finance 101. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2536678

Robertson, L. J. (2000). Twelve tips for using a computerized interactive audience response system. *Medical Teacher*, 22(3), 237–239. https://doi.org/10.1080/01421590050006179

Rutherford, F. J., & Ahlgren, A. (1990). *Science for all Americans*. Oxford University Press.

Sadler, D. R. (1989). Formative assessment and the design of instructional systems. *Instructional Science*, 18(2), 119–144.

Sapp, M. (2013). *Test Anxiety: Applied research, assessment, and treatment interventions*. University Press of America.

Schell, J. A., & Butler, A. C. (2018). Insights From the Science of Learning Can Inform Evidence-Based Implementation of Peer Instruction. *Frontiers in Education*, 3. https://doi.org/10.3389/feduc.2018.00033

Schwartz, D. L. (1995). The Emergence of Abstract Representations in Dyad Problem Solving. *Journal of the Learning Sciences*, 4(3), 321–354. https://doi.org/10.1207/s15327809jls0403_3

Schwarz, B. B., Neuman, Y., & Biezuner, S. (2000). Two Wrongs May Make a Right ... If They Argue Together! *Cognition and Instruction*, 18(4), 461–494. https://doi.org/10.1207/S1532690XCI1804_2

Seymour, E., & Hewitt, N. M. (1997). *Talking about leaving: Why undergraduates leave the sciences*. Westview Press.

Sharma, M. D., Khachan, J., Chan, B., & O'Byrne, J. (2005). An investigation of the effectiveness of electronic classroom communication systems in large lecture classes. *Australasian Journal of Educational Technology*, *21*(2). https://doi.org/10.14742/ajet.1330

Shavelson, R. J. (1996). *Statistical reasoning for the behavioral sciences* (3rd ed). Allyn and Bacon.

Siau, K., Sheng, H., & Fui-Hoon Nah, F. (2006). Use of a Classroom Response System to Enhance Classroom Interactivity. *IEEE Transactions on Education*, *49*(3), 398–403. https://doi.org/10.1109/TE.2006.879802

Smith, M. K., Wood, W. B., Adams, W. K., Wieman, C., Knight, J. K., Guild, N., & Su, T. T. (2009). Why Peer Discussion Improves Student Performance on In-Class Concept Questions. *Science*, 323(5910), 122–124. https://doi.org/10.1126/science.1165919

Snyder, T. D. (Ed.). (1993). *120 Years of American Education: A statistical portrait*. U.S. Department of Education Office of Educational Research and Improvement.

Southerland, S. A., & Gess-Newsome, J. (1999). Preservice teachers' views of inclusive science teaching as shaped by images of teaching, learning, and knowledge. *Science Education*, 83(2), 131–150. https://doi.org/10.1002/(SICI)1098-237X(199903)83:2<131::AID-SCE3>3.0.CO;2-X

Spencer, S. J., Logel, C., & Davies, P. G. (2016). Stereotype Threat. *Annual Review of Psychology*, 67(1), 415–437. https://doi.org/10.1146/annurev-psych-073115-103235

Steele, C. M., & Aronson, J. (1995). Stereotype threat and the intellectual test performance of African Americans. *Journal of personality and social psychology, 69*(5), 797.

Sun, J. C.-Y., & Hsieh, P.-H. (2018). Application of a Gamified Interactive Response System to Enhance the Intrinsic and Extrinsic Motivation, Student Engagement, and Attention of English Learners. *Journal of Educational Technology & Society*, 21(3), 104–116. JSTOR.

TechNavio. (2016). *Global Interactive Response Systems Market 2016-2020* (Market Report No. IRTNTR10838). Retrieved from TechNavio website: https://www.technavio.com/report/global-education-technology-global-interactive-response-systems-market-2016-2020

Terrion, J. L., & Aceti, V. (2012). Perceptions of the effects of clicker technology on student learning and engagement: A study of freshmen Chemistry students. *Research in Learning Technology*, 20(2), 16150. https://doi.org/10.3402/rlt.v20i0.16150

The Learning Center. (2019). *Clicker Questions*. Washington University in St. Louis. https://teachingcenter.wustl.edu/resources/active-learning/active-learning-with-clickers/clicker-questions/

Tim Gordon. (2019, April). Turning Point Technologies [In-person].

Trees, A. R., & Jackson, M. H. (2007). The learning environment in clicker classrooms: Student processes of learning and involvement in large university-level courses using student response systems. *Learning, Media and Technology*, 32(1), 21–40.

Troncoso Skidmore, S., & Thompson, B. (2013). Bias and precision of some classical ANOVA effect sizes when assumptions are violated. *Behavior Research Methods*, 45(2), 536–546. https://doi.org/10.3758/s13428-012-0257-2

Turning Technologies. (2019). Inc.Com. https://www.inc.com/profile/wingstop

Turpen, C., & Finkelstein, N. D. (2007). Understanding How Physics Faculty Use Peer Instruction. *AIP Conference Proceedings*, 951(1), 204–207. https://doi.org/10.1063/1.2820934

Vickrey, T., Rosploch, K., Rahmanian, R., Pilarz, M., & Stains, M. (2015). Research-Based Implementation of Peer Instruction: A Literature Review. *CBE—Life Sciences Education*, *14*(1), es3. https://doi.org/10.1187/cbe.14-11-0198

Webking, R. and F. Valenzuela. (2006). Using audience response systems to develop critical thinking skills. In D.A. Banks (Ed.), *Audience response systems in higher education* (pp. 127-139). Hershey, PA: Information Science Publishing.

Wit, E. (2003). Who wants to be… The Use of a Personal Response System in Statistics Teaching. *MSOR Connections*, *3*(2), 14–20. https://doi.org/10.11120/msor.2003.03020014

Walklet, E., Davis, S., Farrelly, D., & Muse, K. (2016). The impact of Student Response Systems on the learning experience of undergraduate psychology students. *Psychology Teaching Review*, 22(1), 33-48.

Yeh, S. S. (2009). Class size reduction or rapid formative assessment?: A comparison of cost-effectiveness. *Educational Research Review*, 4(1), 7–15. https://doi.org/10.1016/j.edurev.2008.09.001

Zeilik, M., & Morris, V. J. (2004). The Impact of Cooperative Quizzes in a Large Introductory Astronomy Course for Non-Science Majors. *Astronomy Education Review*, 3(1), 51–61. https://doi.org/10.3847/AER2004006