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Factors that promote success in large enrollment general chemistry courses taught with clickers

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FACTORS THAT PROMOTE SUCCESS IN LARGE ENROLLMENT GENERAL CHEMISTRY COURSES TAUGHT WITH CLICKERS.

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ABSTRACT

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The environment of a large (>300) enrollment first semester general chemistry course taught with clickers was characterized by statistical analysis of historical data, as well as through classroom observations and interviewing of professors and students. Four professors with experience teaching chemistry courses with clickers at this university were selected through purposeful sampling and interviewed. A total of 23 classroom observations were conducted. Data was collected from eleven students through interviews, emails, and focus groups. At the conclusion of the interview, students were categorized as field dependent, field intermediate, or field independent using a hidden figure test. Focus groups were assigned to represent one primarily field dependent group and one primarily field independent group. Interview, email, and focus group transcripts were analyzed until a theory of student interactions emerged. Student interactions are self-assembled, and the success of these interactions seems to be driven by the behavior of resonators: students who move throughout the classroom seeking interactions which maximize student learning.

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“Reason's last step is the recognition that there are an infinite number of things which are beyond it."

-Blaise Pascal

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CHAPTER I

INTRODUCTION

Clickers are a recent technological development that allows students to provide instantaneous feedback to instructor questions by the instructor through remote control devices. Clickers have attracted a large amount of interest from teachers across the curriculum and at various stages of development, from secondary classrooms (Hanley & Jackson, 2006; Hsu, 2003; Steele, 1998; Trotter, 2005) to university classrooms (Hafner, 2004; Roschelle, Penuel, & Abrahamson, 2004) to industry (Horowitz, 1988). The interest appears to be growing, as one million clickers were used in classrooms in 2004, and eight million are projected for 2008 ("Interactive clickers can increase student responses", 2006). Several books (Duncan, 2005; Landis, Ellis, Lisensky, Lorenz, Meeker, & Wamser, 2001; Mazur, 1997) have been written for teachers on the use of the technology and the pedagogical methods to accompany it, and the National Resource Council identified clickers as a promising new trend in education (Bransford, Brown, & Cocking, 2000). Anecdotal evidence exists in the fields of astronomy (Duncan, 2006), biology (Brewer, 2004; Carnevale, 2005; Draper, 2004; Hatch, Jensen, & Moore, 2005; Wood, 2004), chemistry (Gaddis, Asirvatham, Schoffstall, & Augenstein, 2006; Ward, Reeves, & Heath, n.d.), geology (Wampler, 2006), computer science, psychology,

statistics, dentistry, veterinary science (Draper, 2004), engineering ("Clicking for scholars", 2005), medical fields (Draper, 2004; Paschal, 2002; Skiba, 2006), and physics (Burnstein & Lederman, 2001; Draper, 2004; Thacker, 2003; Wieman & Perkins, 2005) that both students and teachers have had positive experiences with clickers. These results have been summarized in a review article (MacArthur & Jones, 2008). Recent published research does show some definite benefits of clickers, but there is a need for much more work in the field.

I first heard of clickers in 2002 while attending the Colorado School of Mines (CSM) in pursuit of my master's degree. Dr. Susan Kowalski of the CSM physics department gave a seminar on the usefulness of clickers in physics education. I was very interested, and was pleased to have the opportunity to use the technology in an introductory chemistry course I taught at Red Rocks Community College the following year. Some of my colleagues, however, were skeptical, as the student body of a community college is typically much more diverse than that of an engineering school. The assumption was that clickers would work better in a more homogeneous population, as students in a community college class typically have widely varying abilities: the exceptionally bright students would be easily bored while waiting for others to answer, yet the exceptionally slow students would not be able to keep up. This was an interesting speculation, and would provide the inception for my research questions.

Many variables could affect the viability of clicker technology as it is moved from one institution to another: class size, demographics of student population, instructor background, among others. It is beyond the scope of this study to investigate the effect of institutional context; however, by examining the effect of the technology on varying

student demographics, useful information might be gained that would aid instructors in determining the usefulness of the technology within the context of the courses they might teach.

Perceived Benefits and Drawbacks of Clicker Use

Many articles have been written about perceived benefits of clickers in a variety of disciplines. These perceived benefits, along with perceived drawbacks, class size, technology used (if specified in the publication), discipline, and methods advocated, are listed in Table 1 (reproduced from MacArthur & Jones, 2008) for 18 papers on the practical use of clickers. Most of these papers include details on the implementation of clickers for the specific system being used. There were three papers each from biology, physics, and medical applications, two from nursing, and one from each of the other disciplines listed. These benefits have been summarized previously (MacArthur & Jones, 2008).

The most widely noted benefits that clickers provide are support for formative assessment (N = 10, student collaboration (N = 8), providing anonymous responses (N = 7), taking attendance (N = 4), and quizzes (N = 4). Five papers cited Peer Instruction as a method that is useful with clickers.

Table 1: Observations made in publications on the use of clickers in college level science courses.

Paper	Discipline	Class Size	System Used	Methodology Cited	Benefits	Drawbacks
Brewer, 2004	Biology	large enrollment	PRS	Peer Instruction	Feedback to instructor; students "calibrate" their understanding against the rest of class	
Burnstein & Lederman, 2001	Physics	55	Fleetwood Furniture Company	Peer Instruction	Students like; gauge student preparation; student attentiveness; formative assessment; student collaboration; student feedback on pedagogy; attendance	Less lecture time; adjustment for instructor; technical problems
Carnevale, 2005	Biology	not indicated	eInstruction		Formative assessment; take attendance; quizzes; attentiveness	Some students don't like being tested every day
Duncan, 2006	Astronomy	not indicated	H-ITT	Peer Instruction	Pre-assessment; measure student attitudes; reading quizzes; confront common misconceptions; transform demonstrations; increase students’ retention; formative assessment; facilitate grading; facilitate testing of conceptual understanding; facilitate class discussion; increase attendance	Technical problems; cheating; student expectations of what a lecture should be; instructor discomfort and lack of preparation; covering less material; cost to students

Paper	Discipline	Class Size	System Used	Methodology Cited	Benefits	Drawbacks
Gaddis, Asirvatham, Schoffstall, & Augenstein, 2006	Chemistry	800+	not indicated		Anonymous feedback; interactive and engaging; increased attendance; easy grading; fosters collaboration; inexpensive, easy to use; increase student accountability	Takes lecture time; limited answer format; trivial questions encourage superficial learning; frustration; cheating: punitive
Hatch, Jensen, & Moore, 2005	Biology	25-160	not indicated		Formative assessment; quizzes	Technical problems
Homme, Asay, & Morgenstern 2004	Medical fields	not indicated	not indicated		Interactivity; anonymity; formative assessment; increased attendance	
Julian, 1995	Physics	100+	Classtalk	Socratic	Simultaneous feedback; engaging entire class	
Lightstone, 2006	Accounting	not indicated	eInstruction (CPS)		Active engagement of students; instructor flexibility; formative assessment	Cost to students; need to align with textbook publisher; registration of clickers; slows rate of class
No Author, 2005	Engineering	not indicated	not indicated	Assessment centered	Formative assessment; student collaboration	Not all students support technology

Paper	Discipline	Class Size	System Used	Methodology Cited	Benefits	Drawbacks
No Author, 2005	Nursing	45	eInstruction		Anonymity, fun, immediate feedback, formative assessment	
Roberts, 2005	Library courses	~35	not indicated		Attentiveness, formative assessment, fun	
Robertson, 2000	Medical fields	not indicated	IML Question Wizard	provides 12 tips	Fosters student collaboration question design is important	Technical problems, can be overused.
Skiba, 2006	Nursing	150+	not indicated	Chickering & Gamson's best practice	Anonymous feedback; easier than asking for show of hands; encourages active learning; encourages student-faculty interaction; encourages student cooperation; prompt feedback	
Steinert & Snell, 1999	medical fields	not indicated	not indicated		Attentiveness; instant feedback; anonymous	Can be too gimmicky; time for preparation; limit to question types
Wampler, 2006	Geology	140	not indicated		Wireless R.F. system recommended; integrating clicker software with powerpoint saves time; take attendance; increased student participation	Limited response options; students can't review responses

Paper	Discipline	Class Size	System Used	Methodology Cited	Benefits	Drawbacks
Wieman & Perkins, 2005	Physics	200	not indicated	Peer Instruction	Anonymous responses, accountability of students, fosters student collaboration, enhances communication in classroom, students become invested in learning, reading quizzes	Students don't like use as a testing device.
Wood, 2004	Biology	75	not indicated		Formative assessment; facilitates student collaboration; anonymous responses; increased student inclusiveness, increased student engagement; take attendance	"Big Brother"; forces students to participate; instructor's tolerance for "chaos" in classroom

The most widely noted drawbacks are time limitations (N = 5), student adjustment (N = 5), technology issues (N = 4), instructor adjustment (N = 3), and limitation of question format (N = 3). Some student adjustment issues are worries about "Big Brother," not wanting to be tested every day, being forced to participate in class, and prior expectations of what a lecture should be. Instructor adjustment issues include setup time, availability of suitable clicker questions, and dealing with "chaos" in the classroom. Some of the technology difficulties reported were disappearing clickers, IR systems requiring verification by user (Burnstein & Lederman, 2001), formatting difficulties with software (especially subscripts and superscripts), incompatibilities with platform used, setup time, student difficulties obtaining clickers, devices that are not reliable enough for summative assessment, and problems that arise when the equipment is not permanently installed in the classroom (Hatch *et al.*, 2005).

While the benefits do sound attractive, there is evidence that clickers alone are not enough to create a significant change in student learning (Judson & Sawada, 2002), but significant improvement has been observed when clickers are coupled with an instructional method centered on peer instruction (Crouch & Mazur, 2001). It is this perceived increase in student involvement fostered by clickers that will be the primary focus of this study.

Field Dependence-Independence and Student Learning

Field dependence-independence (FDI) measures a person's ability to isolate key attributes (field independence) out of a field as opposed to their ability to focus on the attributes of the field as a whole (field dependence) (Witkins, Moore, Goodenough, & Cox 1977). Field dependent people are more aware of social cues, more easily influenced by others, will learn better if the material has social content, if they are supplied with an external source of reinforcement on the learning process, and if the information is presented in a previously organized format (Atwater, 1994; Witkins, *et al.*, 1977). Field dependent students are at a disadvantage if the learning environment is not structured (Witkins *et al.*, 1977; Zhang & Sternberg, 2007). Teaching methods that rely on student interaction might be expected to provide a greater benefit for field dependent students due to their reliance on social cues. On the other hand, this approach may often produce a less structured format and could hinder student learning.

Research Setting

The research was carried out with students enrolled in general chemistry at the University of Colorado (CU) in Boulder, Colorado. CU has large-enrollment general chemistry courses. There are typically three sections in the fall ranging in size from 200 to over 300 students. There have been a number of changes in the methods used to teach this course in the six years since clickers were first implemented. In the fall of 2003, the instructors began team teaching the course and using clickers. The team teaching

consisted of several instructors teaching one portion of all three sections of the course. Prior to this, different instructors had been assigned to teach different sections and clickers were not used. In the fall of 2006, several other changes were made to the course: there was an increased focus on molecular visualization, and Chem Concept Challenge Questions were introduced into the recitation sections. In the fall of 2009, one section of the course was taught for chemistry majors and two sections of the course were taught for non-chemistry majors. The two non-chemistry major sections were taught by the same professor, who taught the entire course as opposed to team teaching a section of it. Classroom observations and professor interviews were conducted in the fall of 2008 when there were three sections team taught by two professors. The student volunteers who participated in this study were drawn from the courses in the fall of 2009. The professor of the course from the fall of 2009 is one of the professors interviewed the previous year. Previously existing data from 2001-2007 were also analyzed as well.

Research Questions

Q1 Are there demographic factors that correlate differently with student performance in classrooms that make use of clickers compared to classrooms that do not use clickers?

Q2 What are the similarities and differences in the philosophical approach of professors who have used clickers to teach large general chemistry courses?

Q3 What are the opinions of field-dependent student volunteers regarding how clickers are used in large enrollment general chemistry courses?

Q4 What are the opinions of field-independent student volunteers regarding how clickers are used in large enrollment general chemistry courses?

Q5 What themes are similar between these two populations, and what themes are different?

There has been a recent increase in the use of clickers in large enrollment science courses because they are believed to increase student engagement with the material. Field-dependent learners are less likely to choose careers in science and are also more easily influenced by opinions of others when making decisions (Atwater, 1994). Teaching methods used in a science course that increase students' engagement with each other and with the material might improve student perceptions of the field of science among field-dependent students.

I tested these research questions primarily by using qualitative methods. Student volunteers were interviewed and then given a cognitive test to group them as either field dependent or field independent. Focus groups of each student type met to discuss their experiences in the class, and also provided feedback via email a few times throughout the semester. The correlations between demographics and student performance will be analyzed with multiple linear regression applied to previously existing data.

Limitations

Both the quantitative and qualitative portions of the study had limitations. Although multiple linear regression was used to model trends in student behavior in the quantitative part of the study, no actual experiment was performed in gathering these data, and as such the results of this are not generalizable. All the qualitative portions of the research are limited in their scope to the specific institution under consideration, and

very different opinions would likely emerge from both professors and students if a similar study were conducted at a different institution. There were only 11 student participants and they were placed into three categories. So each category contains only a small number of participants, from three to five. This is too small a sample to make generalizations of all students in these categories.

Definitions

"*Assessing-to-Learn*" (A2L) (also known as question-driven instruction (Beatty, Gerace, Leonard, & Dufresne, 2005) is a method for teaching with clickers developed by physics educators at the University of Massachussets (Dufresne & Gerace, 2004). Students worked in groups, selected answers, and then discussed the answers as an entire class. Approximately 40% of the time was spent as traditional lecture, 30% working in groups, and 30% discussing answers as a class. This method differs from peer instruction in that it does not begin with students working as individuals, and it ends with an entire class.

Clickers have been called by a large number of names throughout the literature: Audience Paced Feedback (APF), Classroom Communication Systems (CCS), Personal Response Systems (PRS), Electronic Voting Systems (EVS), Student Response Systems (SRS), Audience Response Systems (ARS), polling systems, and voting-machines. It is entirely possible that more names for them will appear in forthcoming articles. Clicker technologies enable students to provide instantaneous feedback to instructor questions via a hand-held device. The instructor then has the option of displaying a histogram of

student responses. Typically, clickers are remote control devices making use of either infrared or radio frequency information transfer, but other technology can produce a similar effect. Some alternate delivery methods include hardwired systems (Shapiro, 1997), laptop computers (Pargas, 2005), PDAs (Beuckman, Rebello, & Zollman, 2007), cellphones (De Lorenzo, 2009) or the internet (Ward *et al.*, n.d.; Bunce, VandenPlas, & Havanki, 2006). Some in-house systems have been developed (Shapiro, 1997; Shotsberg & Vetter, 2001), but a number of reasonably priced systems are available commercially (http://www.h-itt.com, http://www.einstruction.com, http://www.iclicker.com). Different clicker systems vary in the way they accept feedback from students as individuals or groups, but there will be no attempt here to make a distinction in this regard when it comes to naming the technology. Barber and Nius (2007) provide an excellent review of the benefits and drawbacks of currently available systems. The key consideration in terms of this study is that the device is able to perform two key operations: allow instantaneous and anonymous feedback from the entire class, and analyze this feedback instantaneously to create a histogram of responses the teacher has the option of presenting to the class.

ConcepTests are multiple choice questions that test student understanding of a concept. They typically do not require more than rudimentary levels of computation, but should require a deep level of thinking to engage the student in the concept. They should be sufficiently different from material covered in class, so the student can not parrot previously covered material. Anecdotal evidence suggests a well written ConcepTest will be answered correctly by roughly half the class (Boyle & Nicol, 2003; Crouch & Mazur, 2001). There are a number of books (Landis *et al*., 2001; Mazur, 1997) and

websites (Herzfeld Group, 2006; Mazur Group, 2006; Robinson & Nurrenburn, 2006; University of Wisconson-Madison Chemistry Department, 2006) devoted to ConcepTests. Many professors who use clickers regularly in their instruction refer to any question used with the clicker as a ConcepTest question, regardless of how closely it relates to previously covered material, and how much of the class is capable of getting the correct answer.

Field Dependence/Independence (FDI) measures a person's ability to isolate key attributes (field independence, FI) out of a field as opposed to their ability to focus on the attributes of the field as a whole (field dependence, FD) (Witkins, *et al.*, 1977). Field-dependent people are more aware of social cues, more comfortable being closer to others when communicating, more easily influenced by others and more affected by the decisions of authority figures, whereas field-independent people are less influenced by others, more comfortable being farther away from others when communicating, and less influenced by authority figures (Atwater, 1994; Witkins, *et al.*, 1977). Field-independent learners generally perform better academically, particularly with problem solving and programming (Zhang & Sternberg, 2007). Field-independent learners are more likely to pursue careers in science and mathematics, whereas field-dependent learners are more likely to pursue careers in teaching (Witkins, *et al.*, 1977, Zhang & Sternberg, 2007). The different cognitive styles will have an effect on the way in which students learn. Field-dependent students will learn better if the material has social content, if they are supplied with an external source of reinforcement on the learning process, and if the information is presented in a previously organized format (Witkins, *et al.*, 1977). Field-

dependent students are at a disadvantage if the learning environment is not structured (Witkins, *et al.*, 1977; Zhang & Sternberg, 2007).

Formative assessment is the use of an assessment as a method of improving teaching and providing students with feedback on their understanding of the subject matter (Nitko & Brookhart, 2007). If students are graded on their performance, it is not considered to be formative assessment, but summative assessment.

Interactors is a term I use to describe particular ways in which students might interact or fail to interact with each other in a large enrollment (>100) course taught with clickers. Students may change from one type of interactor to another. Results of this study as well as my own experience teaching interactive classrooms suggests there are at least four types of interactors: Friends, Loners, Scavengers, and Resonators. Friends interact based on relationships which exist outside of the class. Loners tend not to interact because they are confident in their own answers. Scavengers try to overhear correct answers or coerce them out of other students. Resonators tend to initiate interactions in which information is exchanged between students to facilitate learning.

Peer instruction is a method of teaching advocated by Harvard physics professor Eric Mazur (1997). It involves spending a significant amount of lecture time having students solve problems either individually or as groups. After a short presentation on a topic, students are presented a ConcepTest, given time to think about it and formulate an answer as individuals, and then work in groups discussing their answers. After individual work and group work, students report their answers to the instructor, usually using clickers. A significant percentage (40% or more) of class time is devoted to using peer

instruction. Students are expected to read materials before class, and there is less class time devoted to solving mathematical problems.

Student collaboration is a more general term than peer instruction. In this study it is used to refer to any setting in which students are allowed to discuss answers to a question. It is often unclear from the literature at what level this is occurring when it occurs in a classroom, so a separate definition will be used for more informal or unclear results as compared to the well defined method of peer instruction.

Significance of Study

As mentioned earlier, classroom applications of clickers are a fast growing trend in science education. A number of reports regarding their success in increasing student learning of concepts have been published in the field of physics education, as will be discussed in chapter II. Although there has been considerable interest in using clickers in chemical education, as evidenced by the full symposia on polling systems in chemistry classrooms at many of the recent chemistry education conferences (for example King & Joshi, 2007; Mundel & Ferguson, 2008), research publications on using clickers in chemistry classrooms are sparse. Many of the conference presentations are simply about implementing the technology: how to set it up, what sorts of questions to use with it, novel applications, etc. Few instructors have reached the stage of performing research on the use of clickers in their classrooms. The lack of published research findings is probably in large part due to the fact that implementation of the technology into the

classroom is no small task. Although there have been reports of “contingent teaching,” for example (Draper & Brown, 2004), most of the research studies on how clickers have affected student learning have occurred when a complete transformation of the entire teaching method has occurred along with it. This can be a slow process, and research on classrooms after these changes have fully occurred will be slow in coming.

There is abundant interest in the use of clickers in chemistry, but the opportunities to test its importance are slow in developing. Fortuitously, it was possible to conduct this research study in one of the few research universities which has made a major commitment to teaching with clickers. This study is undertaken at an institution that has already gone through the process of adopting a clicker technology and the changing pedagogical styles that go with it, and has been actively using clickers in its chemistry classrooms for six years now.

FDI is the most widely used cognitive test of all time, and has been found to differentiate students based on their performance in science courses, with field independent students typically performing better. Field dependent people are typically more aware of social cues, but are also less likely to learn well in a chaotic environment. Based on the typical teaching methods used with clickers, these might appear to be conflicting predictors of what is likely to occur. Teaching with clickers often relies on increasing socialization among students, but this can often create a chaotic environment. Which is the more dominant effect? Although there is no controlled study here in which comparisons are made between groups of students with and without clicker use, comparison of FI and FD student opinions of how the clickers are used and their reports of how they react to and use them are very informative.

CHAPTER II

LITERATURE REVIEW

This research will focus on interactions between students, field dependence/field independence (FDI), the use of clickers, and student performance in chemistry courses. Previous work has been published on the interaction between clickers and student performance in chemistry courses, as well as the effect of FDI on student performance in a number of disciplines. But there is no known work connecting all three of these characteristics. This literature review will summarize previous findings of research done on student interactions in the teaching of chemistry, clickers, and FDI.

Student Interactions in Teaching Chemistry

Teaching methods that encourage students to interact with one another are believed by chemical educators to be highly successful (Herron, 1996). There has been a focus on increasing active learning methods used in chemistry courses within the past decade (Campbell & Smith, 1997; Nurrenbern & Robinson, 1997). A variety of methods have been developed, including cooperative learning (Kogut, 1997; Geiger, Jones, & Karre, 2008), guided inquiry (Farell, Moog, & Spencer, 1999), small group learning (Cooper, 2005; Nurrenbern, 2004), process workshops (Hanson & Wolfskill, 2000),

group discussions (Eybe & Schmidt, 2004), peer-led-team learning (Gosser, Cracolice, Kampmeier, Roth, Strozak, & Varma-Nelson, 2001), and process oriented guided inquiry labs (POGIL), (Moog & Spencer, 2008). Such methods emerge directly from the theory of social constructivism (Herron, 1996).

According to social constructivist theory, knowledge is actively created in the mind of the learner (as opposed to being received passively) and this knowledge creation is facilitated by interactions with others (Herron, 1996). Social constructivism emerged from the work of Vygotsky, who claimed that learning occurs through shared experiences (1978). Prior to Vygotsky, Boocock found that groups typically work better than individuals when there is a correct answer to a problem (1972). Postmodern constructivist perspectives regard learning as inherently social, and therefore an individual (such as a teacher) can not be the center of knowledge (Palinscar, 1998). A social constructivist perspective shifts the focus from the teacher to the learner, and furthermore focuses on fostering collaboration between learners. It is in this collaboration that learning occurs.

A significant increase in student understanding of concepts has been shown to occur when interactive methods are used to teach science courses (Cooper, 1995; Hake, 1998). Hake analyzed the Force Concept Inventory (FCI) results in 62 introductory physics courses at various high schools, colleges, and universities totaling more than 6,000 students (1998). Forty-eight of the courses used some form of interactive engagement, while fourteen did not. (Interactive engagement would include any course which includes activities that promote interaction between students.) Students enrolled in the courses using interactive engagement showed an improvement in conceptual

understanding two standard deviations above those in courses that did not use interactive engagement. Hake uses a method called normalized gain to measure this improvement, and his study was a meta-analysis of many physics courses taught at a number of different universities. Normalized gain measures the increase in a student's performance on a standardized test at the end of the course in comparison to the start of the course. As will be discussed below, the majority of research on the use of clickers in teaching at the college level has focused on using them as a method of facilitating student interactions.

Clickers

A literature search revealed 76 papers on the use of clickers that were reviewed in a publication (MacArthur & Jones, 2008). The papers retrieved were placed in categories: articles on the practical use of clickers in college level courses (N=19), applications in middle school or high school settings (N=9), articles on technology issues such as installing a system (N=5), research articles (N=37), and review articles (N=7). Additionally, six books that either provide instruction in the use of clickers or contain sample questions to be used with clickers are available (Asirvatham, 2009; Banks, 2006; Duncan, 2005; Freed, 2010, Landis *et al.*, 2001; Mazur, 1997).

Of the seven review articles referenced, one focuses almost exclusively on papers written in the 60s and 70s (Judson & Sawada, 2002), one is an early review giving examples of six diverse uses of clickers (Abrahamson, 1998) one reviews currently available technologies (Barber & Njus, 2007), one is a study done by a university for the purpose of deciding whether to adopt the technology (Simpson, n.d.), one is a

comprehensive article on the practical use of clickers in biology classrooms (Caldwell, 2007), one is a substantial review for Australian audiences (Kay & LeSage, 2009), and the final paper is a broad review, encompassing non-university work and non-science courses, but does not contain references for all the studies reported (Roschelle, *et al.*, 2004). None of these reviews focused on chemistry instruction.

Articles were categorized as research articles if they contained a report of a research study, such as a quantitative measurement of student performance compared to student performance with another classroom delivery method, interviews of students, or other data. Articles that did not include any of these but did contain useful information based on experience teaching with clickers were categorized as practical applications. The implications of these articles are discussed in Chapter I.

Early Use of Clickers

Despite the recent popularity of clickers, they are not a fundamentally new technology. Technologies similar to clickers were used in the 60s and 70s. These were hardwired systems that were typically made in-house, and were more cumbersome than the modern technology. Research on the effectiveness of these systems showed no measurable gain over regular classroom instruction, even though students had positive attitudes towards the devices (Judson & Sawada, 2002). It is possible that the positive attitudes of students decreased attrition, and thereby lowered the overall scores compared to the control group (Casanova, 1971). The earlier systems were typically used as quizzing devices, and the discussion was limited to communication of student answers to the instructor as opposed to class discussions of them (Ward *et al.*, n.d.), although there is

at least one report of these devices "accidentally" fostering student collaboration (Littauer, 1972).

Because the devices of the time were much more unwieldy than those of today, the technology was discarded for the most part, as the time and money necessary to install and use them did not justify the low impact they seemed to have on student achievement. Today these devices can be created much more easily (Shapiro, 1997; Shotsberger & Vetter 2001; Ward *et al.*, n.d.) and commercial systems are readily available. Although this sort of technology is more easily adopted today than it was thirty years ago, there might be important lessons to learn from its previous failures. Care should be taken not to read too much into the early excitement of students upon the introduction of clickers, as there is likely a Hawthorne effect at the introduction of such a novel device (Poulis, Massen, Roberts, & Gilbert, 1998).

Modern Use of Clickers

Modern use of clickers began after the work of Horowitz (1988). Horowitz observed students with and without the use of clickers in an industrial training course for managers, and found that the students were more attentive and had higher test scores in the courses using a clicker prototype than in those taught with traditional methods. After the work of Horowitz, clicker-like technology became more widespread in college classrooms, and publications on the successful use of clickers began to appear in the mid to late 1990s as commercial products became available. The twenty-first century has seen an increased proliferation of such reports. The majority of research performed on the

use of clickers in science courses has focused either on formative assessment or student collaboration.

Research on Formative Assessment

A number of studies have compared clicker courses to courses taught with a different method, and focused on formative assessment as one of the reasons for the observed improvement. Poulis and coworkers (Poulis, *et al.*, 1998) collected data over a 13 year period in chemistry, physics, and various engineering courses. When clickers were used (N = 2550), the pass rate was 85%, and when clickers were not used (N = 2841), the pass rate was 60%. Although they do not have any data to support this ranking, they list the following possible causes of improvement in expected order of decreasing importance: formative assessment, student engagement, student collaboration, and Hawthorne effects.

Hall and coworkers (Hall, Thomas, Collier, & Hilgers, 2005) observed an improvement in student grades when clickers were used in a high enrollment (~600) general chemistry course, although there was no special effort to ensure equivalent grading with previous classes when they began using the clickers. They attribute this improvement to formative assessment, as clickers were used primarily as a quiz to measure student preparation at the start of each class. Student surveys showed that students identified clicker classrooms at statistically significant higher levels with terms such as engaging, learning, and motivational, and traditional classrooms with terms such as "real world." Although the focus of this work was not on student engagement, clickers

were used throughout the lecture to test students on new concepts, and student collaboration was often allowed.

Not all results have been positive. Kennedy and Cutts (2005) analyzed frequency and correctness of student responses in a computer science course. Student collaboration was allowed at times, though it was not a focus of the study. Their results indicated higher achievement in the course for students responding most often with the correct answer, as would be expected. They were unable to find evidence for increased learning due to formative assessment enabled by the use of clickers.

Paschal (2002) conducted a careful comparison of courses with and without use of clickers. The experimental group was given in-class questions using clickers, and four quizzes on reading assignments. The control group did not have in-class questions or reading quizzes, but did have homework assignments. There is no indication that student collaboration occurred. The experimental group did not perform statistically significantly better than the control group. The author indicates that the results for the experimental group may have been confounded by the 9/11 tragedy.

Bunce and coworkers (Bunce, *et al.*, 2006) compared two sections of the second semester of a chemistry course for nursing majors: one section using clickers was compared to a section using online quizzes taken outside of class. Both methods provided nearly instantaneous feedback. They found no statistically significant difference between the use of online quizzes and clickers. They do indicate that the students may not have been engaged while using clickers, as the responses were displayed as students selected them, and students unsure of what to select could simply vote with the majority.

Research on Interactive Engagement Among Students

Other studies have focused on the use of clickers as a means to promote various forms of interactive engagement among students. As discussed in the section on student interactions, significant increase in student understanding of concepts has been shown to occur when interactive methods are used in science courses (Hake, 1998). Researchers at the University of Massachusetts (Beatty *et al.*, 2006; Dufresne, Gerace, Leonard, Mestre, & Wenk, 1996; Dufresne, Leonard, & Gerace, 2002; Dufresne & Gerace, 2004; Leonard, Dufresne, & Mestre, 1996) and Harvard (Fagen, Crouch, & Mazur, 2002; Crouch & Mazur, 2001; Mazur, 1997) have investigated the use of clickers to promote student interaction in physics courses over a period of many years. More recently, other researchers have adopted these methods (Gaddis, *et al.*, 2005; Holme, 1998; Pollock, 2005a; Towns, Cisneros, Robinson, Weaver, & Wenthold, 2007), compared the methods advocated by these groups (Boyle & Nicol, 2003; Nicol & Boyle, 2003), or proposed other methods that promote student interaction (Reay, Bao, Li, Warnakulasooriya, & Baugh, 2005; Sharma, Khachan, Chan, Stewart, Kirsten, & O'Byrne, 2002; Meltzer & Mannivanan, 2002).

Crouch and Mazur (2001) indicated significant improvement when using peer instruction in a physics course. Data were collected over a period of ten years, in which the physics course was continually refined. Student learning was measured using two standardized physics examinations: the Force Concept Inventory (FCI), and the Mechanics Baseline Test. FCI is a conceptual test involving no computations, and thus was valid as a pretest as it did not require students to make use of equations they had not

yet learned. Normalized gains on the FCI when peer instruction was used (0.49-0.74) increased significantly over results using traditional lectures (0.25), and showed steady improvement as changes were implemented in following years.

The methods used by Crouch and Mazur evolved over time into the following. Peer instruction, as described in chapter I was used: students worked individually and then in groups. One half to one third of the class time was devoted to Peer Instruction, while the rest consisted of lecture. Although Peer Instruction was in place before the introduction of clickers, physics instructors now view the two as being somewhat synonymous (Lasry, 2008). Exams contain conceptual questions in order to indicate the level of importance of concepts in the course. In order to make time for peer instruction in class, either the students are required to read the text ahead of time, or the amount of material covered is reduced, depending on the specific course. The researchers attempted a number of methods in order to motivate students to read for class ahead of time: reading quizzes, written summaries, and an online assignment. The online assignment proved to be the most effective for formative assessment, as it was free response, and gave the instructor some idea of students' misconceptions before class. In addition, students attended weekly workshops on problem solving skills to help them with quantitative problems. They worked in groups on homework problems or the instructor worked challenging example problems for the class. The course was team taught in each case, with a number of different instructors who used the method throughout the years under consideration.

Instructors at other institutions have used PI with some success (Fagen *et al.*, 2002). In a survey of 384 PI users, 303 definitely planned to use it again, while only

seven indicated that they did not plan to use it again. Additionally, normalized gains of 0.39 ± 0.09 were observed on the FCI for 30 physics courses in which PI was used. Six of the 18 practical implementations of clickers mentioned earlier in this paper referenced PI as a useful method (Brewer, 2004; Burnstein & Lederman, 2001; d'Inverno, Davis, & White, 2003; Draper & Brown, 2004; Duncan, 2006; Weiman & Perkins, 2005).

Pollock (2005a) implemented several innovations in a calculus-based physics course, including PI using clickers, tutorials, and online homework. Normalized gains on commonly used standardized tests were greater than 40% on one (Force and Motion Conceptual Evaluation, FMCE), and were greater than 60% on another (FCI). Peer Instruction was used for 30-50% of class time. However, the gains could not be attributed to a single source and the amount of gain diminished when some of the other innovations were removed (Pollock, 2005b). These innovations have subsequently been applied to the education of physics teachers (Pollock, 2005c).

James (2006) observed how levels of student cooperation with PI varied based on whether students got points for answering incorrectly. There was more cooperation among students when equal credit was given for wrong answers than if correct answers received more points. PI with the use of clickers was implemented by two different instructors in two different astronomy classes. In one class (high stakes clicker use), 12.5% of the student's grade was from points for correctly responding to clicker questions, while in the other class (low stakes clicker use), 20% of the student's grade was for responding to the clicker question, regardless of whether they responded correctly or not. Student conversations were monitored with tape recorders and researchers later analyzed these conversations to determine how equally different student

ideas were shared. There was a statistically significant increase in equally shared ideas in the low stakes class, whereas in the high stakes class the conversation tended to be dominated by the more knowledgable students.

Van Dijk, Van Den Berg, and Van Keulen (2001) compared engineering courses without the use of clickers, courses with clickers but no student interaction, and courses with clickers and PI. They found that students attending a lecture with PI, both with and without clickers, showed greater improvement in understanding than students attending a lecture with clickers but with no student interaction. However, this study was done over the course of only one lecture period, and students may not have had sufficient time to adjust to the new teaching methods used for either of the clicker courses.

A couple of studies on methods similar to PI have been carried out in chemistry courses. Holme (1998) used a method modeled on PI in a large general chemistry course, though without the use of clickers. When comparing student answers before and after group discussions, more students (48) changed from incorrect answers to correct answers than changed from correct answers to incorrect answers (4). The results of changes in student selections from individual work to group work were reported for four questions. The initial percentage of correct responses ranged from 25% to 81%, so some were within the range suggested by Mazur and some were both above and below it. Wagner (2009) adapted the methodology proposed by Holme, by including questions as segues between topics or introductions to a new topic.

Towns *et al.* (2007) observed student answers to questions in a large general chemistry course using clickers. The students used a method similar to PI, except that

students did not always use clickers to respond both individually and while working in groups. Group responses were correct significantly more often than individual responses.

Donovan (2008) used a method modeled after PI in teaching a general chemistry course. Comparisons were made between student responses to ConcepTest questions used with the clickers and similar questions on an exam. There was a significant increase in student performance on exam questions similar to the clicker questions used.

Another method of promoting student engagement in a physics course using clickers was developed by Dufresne *et al.* (1996). The students worked in groups, selected answers, and then discussed the answers as an entire class. Approximately 40% of the time was spent as traditional lecture, 30% working in groups, and 30% discussing answers as a class. This method differs from peer instruction in that there is no initial individual work, and at the end some time is spent in entire class discussion. Student opinions were overwhelmingly favorable; however, no quantitative data were collected. This method has subsequently been referred to as “Assessing-to-Learn” (A2L) (Dufresne & Gerace, 2004) or question-driven instruction (Beatty *et al.*, 2005).

Others (Meltzer & Mannivanan, 2002; Reay, *et al.*, 2005) have developed sequences of progressively more difficult questions that lead to peer discussion when the percentage of correct answers dwindles. One of these groups (Meltzer & Mannivanan, 2002) claims to model their approach after both PI & A2L, and though clickers were not used they claim that their results are equivalent to results that they would have had with clickers. They used the color-coded card method (Meltzer & Mannivanan, 1996). Comparisons of clickers and flashcards will be made in a subsequent section of this chapter.

Reay and coworkers used a three-step sequence that included interactive engagement of students and the use of clickers (2005). After the subject was introduced, an initial "warm-up" question was presented, followed by a more difficult conceptual question. In each case, students answered individually. Typically mixed results were obtained after the second question, which prompted a class discussion. The question was asked again after the discussion, and finally a third question of similar difficulty to the second was asked; if results were sufficient, the instructor moved on to the next topic. Student surveys provided positive results. Students using clickers did better on an exam question covering the same material than those taught the material using traditional methods.

Singh compared results when students worked in groups followed by individual work as opposed to working individually followed by group work (2005). The students were given the Conceptual Survey of Electricity and Magnetism (CSEM) in physics, then retook the CSEM two weeks later. No statistical difference was found between the two protocols. Clickers were not used in this study, however it does represent an additional model of student interaction.

Other researchers have compared different models of student interaction (Boyle & Nicol, 2003; Nicol & Boyle, 2003). They alternated between PI and A2L during the same semester. No data on student achievement were collected, but student opinions were obtained through questionnaires, surveys, and interviews. Results indicated that PI was generally the preferred method. Student achievement on ConcepTests was found to be in the range of 40-60%, which is consistent with the difficulty level suggested by Crouch and Mazur (2001).

Research on Selection of Appropriate Questions for Use With Clickers.

Regardless of whether the focus of research on clickers is formative assessment or student collaboration, the selection of questions for use with the clickers is important and some work has been done in this area.

Crouch and Mazur (2001) identify one of the most important aspects of the methods they used as the proper selection of ConcepTests. The tests should be "challenging, but not excessively difficult." They identify a range of 35%-70% of students responding correctly as the goal, with 50% being optimal. Correct answers lower than this range indicate the question is likely too challenging, while percentages above this range indicate the question is not challenging enough to stimulate worthwhile discussion. There are no empirical data supporting what the optimal percentage might be, but the success of this method based on normalized gains suggests that this claim is correct. A number of collections of ConcepTests in various disciplines are available online (Herzfeld Group, 2006; Mazur Group, 2006; Portland State University, 2006; Robinson & Nurrenbern, 2006; University of Wisconson-Madison Chemistry Department, 2006).

The question selection used for the "Assessing-To-Learning" method are created to fulfill a content goal, a process goal, and a metacognitive goal (Beatty *et al.,* 2006; Dufresne *et al.*, 2002; Leonard *et al.*, 1996).

Towns *et al.* (2007) used a wide variety of questions with clickers, and have used Bloom's taxonomy to categorize the types of questions that they used. More recently,

others (Mundell & Ferguson, 2008) have used Bloom's taxonomy to categorize question types as well.

Sharma and coworkers (Sharma *et al.*, 2002) used clickers with student collaboration sporadically in a physics course. Questions for use with clickers were selected by phenomenographical analysis of the previous year's final exams and by creating multiple choice questions that would probe for common student misunderstandings.

As of this writing two books containing clicker questions used in chemistry courses have been published (Landis, *et al.*, 2001; Asirvatham, 2009).

Research on Comparing Clickers to Flashcards

A low-tech method that allows for some of the gains of clickers is the use of color-coded cards to select an answer (Meltzer & Mannivanan, 1996). This approach allows for anonymous responses but does not give the instructor the ability to collect histogram data and display it to the class. This method may be a good option for instructors who would like to use clickers, but do not have the funding necessary to acquire them.

Lasry (2007) compared using clickers to using color-coded cards in a physics course taught at a community college and found no difference in student performance. Peer Instruction was used in each case.

Wimpfheimer (2002) reported that student responses were not as anonymous with cards as they might have been with clickers when used in a small (15 student) general chemistry course.

Research on Student Attitudes with Clicker Use

Barnett (2006) examined student attitudes when clickers were implemented on a large scale in biology and physics courses. Despite a host of technical difficulties, the majority of students had favorable responses, listing feedback, interactivity, and peer comparison as significant reasons why they liked clickers. Difficulties mentioned include technical problems, poor implementation, and wasted class time.

Research suggests that for clickers to be successful, the instructor's focus should be on the students' use and acceptance of the technology, and not the technology itself. Bergtrom (2006) identifies clickers as interactive and learner-centered devices, and reports that they may be particularly useful in enabling critical thinking in large lecture classes. Trees and Jackson (2007) note that the success of clickers is more of a social issue rather than a technology issue, and that the role of the instructor should be to facilitate students' embracing the learning potential the clickers allow. Draper and Brown (2004) surveyed students in a number of courses that used clickers, and discovered that the greatest degree of student apprehension about clickers occurred when students perceived the lecture as being technology-centered rather than focused on the course content. Rice and Bunz (2006) found that students gave more positive feedback on clickers if they had a greater diversity of exposure to technical and social situations prior to the use of clickers. In two of these studies (Trees & Jackson, 2007; Draper & Brown, 2004) the use of clickers was analyzed in both science and humanities courses, but there was no indication of a difference in student attitudes between disciplines of use.

Miscellaneous Research on Clickers

Although the largest portion of published research on clickers focuses on their use to foster student engagement, some studies have considered other possible benefits. Draper and coworkers (Draper, Cargill, & Cutts, 2002; Draper & Brown, 2004) propose that clickers are niche technologies that work best when selected to fill a particular perceived deficiency in a course. Two effective implementations mentioned are the use of clickers to foster student collaboration, and contingent teaching. In contingent teaching, the direction of the lecture is determined by student responses to key questions.

Bunz found clickers to be as valid as scantron forms for testing student knowledge (2005). No student collaboration was used, as the study was judging whether the method of data collection itself was valid, not the effect it had on student performance. Students found the difficulty and time pressure of clickers comparable to that of scantrons. They did find clickers more fun, but were less confident of their answers.

Ruder and Straumanis (2009) have developed an open-ended application of clickers for questions on organic chemistry mechanisms. Open-ended questions might be developed in other areas as well.

Appropriate Theoretical Framework for Clickers

Clickers themselves are merely a tool for instruction that might be used either well or poorly in the classroom. As such, clickers have no more inherent theoretical framework than does a piece of chalk. However the success or failure of a given method

of using clickers might suggest the most appropriate theoretical framework to use in developing the pedagogy that the clickers will accompany.

The positive results seen for the use of clickers with student collaboration can be linked to an underlying theoretical framework of social constructivism (Dufresne, *et al.*, 1996). As discussed in the section on student interactions, in this theory learning is believed to occur through shared experiences (Vygotsky, 1978).

Let us reconsider the lack of improvement found when clickers were initially used in the 1960s and 1970s. During this time period, a behaviorist learning theory was dominant, and the teaching methods used probably reflected this. Judson and Sawada claim that the improvements in student learning observed in recent studies contrast with the lack of improvement in the earlier studies because student collaboration is being used in the current iteration (2002). All of the studies in this review that showed statistically significant improvement over traditional methods incorporated student collaboration in conjunction with the use of clickers.

In light of this, the comparison between successful uses of clickers and non-successful uses of clickers might suggest the most appropriate theoretical framework for their use. Kennedy and Cutts report that students answered questions correctly in their analysis 75-80% of the time (2005). This is in contrast to the 35-70% range advocated by Crouch and Mazur (2001). When the level of the questions are too difficult, there is insufficient "traction" for the students to have a productive dialogue on the correct approach, and therefore limited learning can occur. Bunce and coworkers had limited engagement by students due to the display of the histogram while some students were still working (Bunce, *et al.*, 2006). This strategy can be viewed as having the opposite

effect of the approach used in the previous study. Not challenging students enough, or allowing for shortcuts around engaging in ConcepTest questions does not result in learning through student collaboration.

In many cases it was unclear what sorts of student collaborations were occurring in the classrooms under investigation, and what sorts of questions were being asked of the students when they used the clickers. If the students are collaborating in ways that do not engage them with the questions, or if the questions are too easy or too hard, increased student learning through collaboration may not occur. From the literature that has been reviewed, it appears the most successful method yet reported for using clickers is peer instruction (as defined in the introduction) using questions that about 50% of the class will answer correctly.

Field Dependence-Independence

The study of field dependence began with a number of tests developed by Witkins and Asch: the rod and frame test (1948a), the tilting room test (1948b), and the embedded figure test (Witkins, *et al.*, 1977). Other tests were also developed that measured auditory and tactile abilities to differentiate an item from a field (Witkins *et al.*, 1977). In the rod and frame test, participants were placed in a completely darkened room and asked to place a laminated rod in a vertical position within a tilted frame (Witkins & Asch, 1948a). Field dependent participants were more influenced by the position of the frame. In the tilting room test, the participant sits in a room that is tilted and must adjust the chair in the room to the vertical position (Witkins & Asch, 1948b). Field dependent

participants were more influenced by the position of the room. Witkins began this endeavor when there was a lot of focus on wartime research on airplane pilots (Riding & Matthias, 1991). Witkin later developed the group embedded figure test (GEFT) to measure field dependence-independence (Witkins, Oltman, Raskin, & Karp 1971). This test had the advantage of being more easily administered in a classroom setting, as it was a pencil and paper test. Probably due to the ease of administration, field dependence-independence soon became the most widely administered cognitive test (Witkins *et al.*, 1977). Its use dropped dramatically in the 1980s, however, partly due to signs that it was correlated with intelligence (Richardson & Turner, 2000).

In the late 80s and early 90s, researchers returned to looking at cognitive styles, often combining many of the previously known styles and claiming that they were all subordinate to a new style that they had developed (Miller, 1987; Riding & Cheema, 1991). This was partly due to trying to form a connection between the waning field of intellectual styles and the emerging field of cognitive processes, and partly due to a desire to have a non-value laden measure (Zhang & Sternberg, 2006). The argument against the GEFT is that the measure of field dependence is based on doing poorly on field independent tasks, whereas there is no measure of how well participants perform on field dependent tasks (Richardson & Turner, 2000; Riding & Mathias, 1991). So a participant who performs poorly on any task would automatically be grouped as field dependent. The Cognitive Styles Analysis (Riding & Mathias, 1991) was designed to measure positive attributes of both field dependence and field independence. The CSA groups participants as either Wholist (analogous to field dependent) or Analyst (analogous to field independent), and the creators of it claim that it encompasses many other intellectual

styles as well (Riding & Pearson, 1995). Participants are timed for each task they complete in a computer simulation and the ratio of the times necessary for the Wholist tasks over the times necessary for the Analyst tasks determines the categorization of the participant.

There is still controversy over which is the better measure. The CSA does not correlate highly with intelligence measures; however, it doesn't correlate highly with the GEFT either (Riding & Pearson, 1995; Rezaei & Katz, 2004). Supporters of the GEFT claim this discrepancy invalidates the CSA, and supporters of the CSA claim it invalidates the GEFT (Riding & Pearson, 1995; Tinajero, Paramo, & Guisande, 2007). Zhang and Sternberg (2007) question the reliability of CSA and whether it encompasses the styles it claims to measure. Tinajero goes so far as to state that "arguments about the validity of assessing field dependence are a futile waste of time" (Tinajero, *et al.*, 2007).

Although the arguments in favor of the CSA are compelling, GEFT is still widely used by researchers across the world, and the paper and pencil format makes it simpler to administer to a large number of participants simultaneously. Particularly, the GEFT has been used to study student performance in mathematics and science. Roth (1990) found that field dependence did not predict student success on either problem solving or recall questions in a physical science course for non-majors. Niaz (1987) found Witkin's cognitive style predictive of success on formal reasoning tasks, though not as consistently as Pascual-Leone's structural M-capacity. Likewise, Lopez-Ruperez, Palacios, and Sanchez (1991) found that field independence correlated only with the portions of a pencil and paper Piagetian test that required formal reasoning, a result consistent with previous findings of correlation between formal reasoning and field independence.

Vaquero, Rojas de Astudillo, and Niaz (1996) found that FDI was correlated with both working memory and structural mental capacity, but that both of these other measures correlated more highly with performance in science courses than does FDI for college freshmen in Venezuela. Chao, Huang, and Li (2003) found that there was a difference between secondary school mathematics teachers and upper division university mathematics students, with the teachers scoring as more field independent. Ates and Cataloglu (2007) found that FDI was related to students' problem solving skills but not to their conceptual understanding in a study of 213 freshmen physics students in Turkey.

There have been studies of FDI particular to the field of chemistry education. Falls and Voss (1985) found that among students in a high school chemistry class, field independent students performed better than field dependent students on problems that required proportional reasoning if the problems contained both relevant and irrelevant information. Niaz and Lawson (1985) used FDI to account for difficulty in disembedding information from potentially confusing questions on balancing chemical equations. Staver and Jacks (1988), on the other hand, performed a factor analysis on the results of several cognitive tests and student ability to balance equations. They found that disembedding, restructuring, and reasoning all loaded on the same factor, and that this factor was the highest predictor of success. Kuo (1995) found that FDI was not as strongly correlated to performance on stereochemistry problems as mental capacity and visualization were. Tsaparlis (2005) found that disembedding skills and functional M-capacity were much more important in student performance on an open book physical chemistry exam than were scientific reasoning skills and working memory capacity.

Although controversy exists about the best way of measuring disembedding skills, and which aspects of learning are most affected by them, there are obviously some differences in the learning experiences of students based on their position on the FDI continuum.

CHAPTER III

METHODOLOGY

This research comprised a mixture of both qualitative and quantitative methods. It was conducted in the general chemistry courses at CU-Boulder. Clickers have been used to teach the large enrollment general chemistry courses at CU-Boulder since Fall 2003. Each research question will be addressed below.

> Q1 Are there demographic factors that correlate differently with student performance in classrooms that make use of clickers compared to classrooms that do not use clickers?

The quantitative portion of the research was not experimental, but consisted of statistical analysis of previously collected data. There was no attempt to control the ways in which the courses were taught. There was neither a control section nor an experimental section. Data on student grades and demographics were provided by CU-Boulder for the year before clickers were used as well as for the first four years of clicker use. The available data included student scores on all exams, final score and grade in the course, declared major, ethnicity, gender, amount of financial aid obtained, level of completion of mathematics, chemistry, and physics courses in high school, student scores on all portions of the SAT and ACT standardized exams, and high school GPA.

A multiple linear regression (MLR) was performed on the student demographic data, the three categories of clicker use (no clickers, clickers with team teaching and a

traditional focus, and clickers with team teaching and a focus on molecular level concepts), and the interaction between the data and the type of use. The dependent variable for the MLR was the total score (total points) in the course. There were 68 independent variables: dummy coded variables for each of 8 categories of major (undecided; molecular cellular and developmental biology; other biology; chemistry and biochemistry; psychology; physics, mathematics and engineering; other sciences; and other majors), dummy coded variables for each of 7 categories of ethnicity (Asian, Black, Hispanic, International, Native American, White, Unknown), gender, family resources, transfer students, standardized mathematics scores, standardized verbal scores, high school GPA, three categories of clicker use, and the interaction between each of these categories and each of the other independent variables. Family resources were coded as receiving financial aid or not. Transfer students were coded based on whether or not data for completion of various levels of high school coursework were present: students without data on high school coursework were coded as transfer students, while those with data were coded as non-transfer students. This was done because the database received from the school indicated that high school coursework data were missing for transfer students. Standardized ACT scores were converted to SAT scores using a concordance equation from the CU-Boulder website (McClelland, 2005). Other concordance tables are available, but the one used by the institution under investigation is most appropriate. The three categories for clicker use are no clickers, clickers with team teaching, and clickers with team teaching and a focus on molecular level concepts. These correspond to the years 2002, 2003-2005, and 2006, respectively. Data for each year were analyzed using PROC GLM in SAS to model the MLR. SAS is a statistical analysis program

available to graduate students at UNC, and PROC GLM is the program used for modeling multiple linear regression. Largely insignificant data were dropped from the model until a simple model for each year was obtained.

Q2 What are the similarities and differences in the philosophical approach of professors who have used clickers to teach large general chemistry courses?

The qualitative portion of the research began with becoming acquainted with the ways in which clickers are used in the general chemistry courses at CU-Boulder. This process consisted of eighteen total observations of four professors who teach general chemistry with clickers at CU-Boulder. After observing these professors, they were also interviewed in order better to understand their teaching methods. Interviews consisted of a brief email interview and a follow-up in-person interview. The in-person interviews were similar but in some cases questions were based on instructor responses to the email interviews, observations made in the professor's class, or unexpected answers to questions of professors interviewed previously. The methodology of this portion of the research is an interpretivistic case study. Interviews were transcribed and transcriptions were analyzed to find themes which characterize ways in which chemistry courses are taught with clickers at CU-Boulder.

Q3 What are the opinions of field-dependent student volunteers regarding how clickers are used in large enrollment general chemistry courses?

Q4 What are the opinions of field-independent student volunteers regarding how clickers are used in large enrollment general chemistry courses?

Q5 What themes are similar between these two populations, and what themes are different?

After gaining a basic understanding of how the courses are taught, the focus then turned to understanding student impressions of clickers. This investigation began with a

pilot study in the spring 2009 semester. Student volunteers were selected from three recitation sections of the general chemistry course at CU-Boulder. Student volunteers took the hidden figure test and filled out a consent form during three of the recitation sections early in the semester. The hidden figure tests were scored, and students grouped as FD or FI (Ekstrom, French, Harman, & Dermen, 1976). Students were contacted through the email address provided on the consent form and asked to participate in the study, with the intent of having two focus groups: one for FD students and one for FI students. Students were initially contacted based on being FD or FI, however there were limited responses, so all students who provided an e-mail address on the consent form were eventually contacted. Of the 45 students who were contacted, six expressed interest in participating, and only three attended one of the two focus groups. The one focus group that actually had two students attend it initially had poor interactions between the students: the female student said she felt overwhelmed because it was the largest class she had ever been in, and the male student then immediately said it was one of the smaller classes he had ever been in. This put a damper on any future interactions. The three participants were asked to email responses about how they did on clicker questions a couple of times throughout the rest of the semester. Both of the female students participated, but the male student did not. Only one additional meeting could be scheduled and only the two females of the original three students attended this meeting. Student participants were compensated with food at each meeting and a gift card at the completion of the study.

Two major conclusions were drawn from the pilot study, both having to do with the logistics of arranging a study: sparse participation, and unproductive focus group

interactions. A change that would address both of these issues might be having initial interviews in which the HFT was administered instead of administering it to the entire course or several recitation sections and hoping for interest from the participants. This method would then allow me to assign focus groups based on student scores on the HFT, and also consider possible group dynamic problems while doing so. Although male to female interactions were not the primary concern at this point, they later became an important consideration. The disadvantage to this method was that it limited control over the overall distribution of students along the FDI spectrum, as there would be an interview accompanying each HFT, and there were not resources available to conduct 45 interviews. However, administering the HFT before soliciting student participants, as was done in the pilot study, did not produce sufficient participation. This might have been because the participant pool was limited to three recitation sections or possibly because the test itself discouraged student interest in the study.

After completing the pilot study, the final research study was conducted in fall 2009 in a lecture section taught by Dr. Thompson, one of the professors who participated in an interview the previous year. Dr. Thompson informed the students in the course of the possibility of participating in the study through the course's website as well as by an email announcement. Initially a large number of students expressed interest in participating, and interviews were scheduled based on availability and order of response to interview time solicitation emails. In the first few weeks 26 students indicated interest in participating in the study: 10 male students, and 16 female students. Eleven interviews were scheduled in the first two weeks, but one female and two male students did not show up for the scheduled interviews. Initially, there were one male and seven female

participants. I decided that more male participants were needed, so three interviews were scheduled for the next week with male participants, only one of whom showed up. At this point, the gender balance of the focus groups was considered, and I decided that it would be best to have only females in the focus groups to ensure that each focus group had the same gender balance: 100% female in this case. The eight female students who had initially expressed interest but had not fit into the initial interview schedule were contacted again, and one of them was available for an interview. This interview occurred the same week as the initial email survey started. As the email surveys continued and participation in them dwindled, I decided that more participants were necessary, particularly as one of the participants informed me that she had dropped the class. I again contacted the remaining seven female students who had expressed interest and had no response. The professor sent out another email to the class soliciting more volunteers. This produced 6 potential participants, 3 male and 3 female. Of these, I was able to interview one of the females. This interview took place after all three email surveys had been sent out, and so this student, Anne, participated only in the interview and the focus group. Student participants were compensated with a gift card for their time.

The initial interview was developed to have mostly very general and broad questions, with the idea that more in-depth data would be available later in the semester through the email responses and the focus group meetings. The interview protocol was reviewed by three other chemical educators before being used, as well as by the IRB reviewer. The other chemical educators were my advisor, my co-advisor, and an educational specialist in the chemistry department at CU-Boulder. A copy of the interview protocol is included in Appendix B. The interviews were audio recorded, and

lasted between 10.5 and 28 minutes in length. They were then followed by administration of the hidden figure test (HFT), which took approximately 25 minutes. Students were grouped into categories of FD, FI, or intermediate based on their performance on the HFT.

Three email prompts were sent out in the weeks following the interviews. The email prompts were identical, but asked questions about the clicker questions Dr. Thompson had used on specific days. They were spaced a few weeks apart, and were asked on different days of the week. A copy of the email prompt is included in Appendix C.

The focus group interview protocol was developed based on student responses to interview and email questions. Questions were devised in part to illuminate any differences in opinions between FD and FI students: the nature of the student collaboration that took place and how they understood the questions. Interviewees were asked to discuss selected student comments. The initial draft of the protocol was revised based on comments from my advisor, and a subsequent revision took place based on comments in a video recorded meeting of the University of Northern Colorado chemical education research group. Video recording this meeting had two benefits: it "took notes" for me on the feedback from the other chemical educators, and it gave me practice at having something like a focus group meeting before actually conducting the focus groups. A copy of the focus group interview protocol can be found in the Appendix.

The participants were grouped into FI and FD categories to arrange for focus group meetings. Because the largest group of students was intermediate, and the available number of students in each of the FD or FI categories was insufficient for a

complete focus group, I decided to have two focus groups, one for FD students and one for FI students, but gather additional students for each group from the intermediate students. Of the three female intermediate students, two were able to participate in the focus groups: Irene, and Mariah. This arrangement generated one focus group with two FD and one intermediate student, and one focus group with two FI and one intermediate student. Both focus groups consisted of only female students. One of the FD students, Rosalind, informed me that she had dropped the course, and one of the FI students, Edith, did not respond to any of the email surveys after the initial interview. I received an email shortly before the start of the FI focus from one of the participants, Dorothy, saying she was sick and unable to participate. So the FI focus group that met was composed of one FI student and one intermediate student.

During the focus group, students were asked to talk amongst themselves about a few questions regarding the use of clickers in their chemistry course. The focus groups lasted approximately fifty minutes, and were both audio and video recorded. Participants in the focus group were compensated with a gift card for their time.

Data collected in this study were analyzed using grounded theory. Additional sources of data that were incorporated into this analysis are the data from observations and interviews of professors. All of these data were analyzed and a theory about self-assembled student interactions was formed.

Researcher Perspectives

According to Creswell (2007) “Qualitative Research is an umbrella concept covering several forms of inquiry that help us understand and explain the meaning of social phenomena with as little disruption of the natural setting as possible”(p. 5). I selected qualitative research as the method for a large portion of this study in an effort to minimize disruption of the natural setting. Classrooms are a dynamic setting, and the complexity of these dynamics might increase drastically as more interactive methods are added to the course. In fact, it may be similar to the increasing complexity of the Schroedinger equation as additional electrons are added. Additionally, ethical considerations mandate minimizing disruptions. The professors at the university where the research is being conducted believe that using clickers has vastly improved their courses. It would be unethical to teach a section with a method the instructor believes to be inferior simply to prove a point. Therefore, a control section would not be appropriate. The goal here is to understand why this improvement has occurred. Cresswell (2007) states “In contrast to quantitative research, which takes apart a phenomenon to examine component parts (which become the variables in the study), qualitative research can reveal how all the parts work together to form a whole” (p. 6).

In order to perform qualitative research, the researchers themselves become the instruments. A good researcher may more fully reveal the details of the phenomenon under investigation than will the application of statistical analysis to bulk samples of data; however, each researcher will have their own perspectives and biases. The goal is not to eliminate these biases, but to reveal them and the associated theories that will

underlie the research. Therefore a discussion of the epistemology, theoretical perspective, methodology and methods of the study is important.

Epistemology is “the theory of knowledge embedded in the theoretical perspective and thereby in the methodology” (Crotty, 1998, p. 3). Many qualitative researchers have a constructionist epistemology (Crotty, 1998). My epistemology is more post-positivist, but pragmatically similar to constructionism, particularly as it applies to the research at hand. “[Postpositivists] admit that, no matter how faithfully the scientist adheres to scientific method, research outcomes are neither totally objective nor unquestionably certain. They may claim a higher level of objectivity and certitude for scientific findings than for other opinions and beliefs, but the absoluteness has gone and claims to validity are tentative and qualified” (Crotty, 1998, p. 40). I believe underlying strands of truth exist independently of the realities constructed in human minds and interactions; however, the exact nature of these truths will remain ever elusive. I will likely (and perhaps unjustifiably so) tend towards generalizations in an attempt to approximate these truths moreso than would a typical constructionist. I do, however, find constructionism useful, particularly for the study at hand, in which the question is not as much about a pervading truth in reality as much as it is about how students go about constructing their own perceptions of this reality. “[Constructionism] is the view that all knowledge, and therefore all meaningful reality as such, is contingent upon human practices, being constructed in and out of interaction between human beings and their world, and developed and transmitted within an essentially social context” (Crotty, 1998, p. 42).

The theoretical perspective of this study is relevant for the qualitative research performed in answering questions 2-5. My theoretical perspective in performing this work was symbolic interactionism informed by critical inquiry. "Critical forms of research call current ideology into question, and initiate action, in the cause of social justice. In the type of inquiry spawned by the critical spirit, researchers find themselves interrogating commonly held values and assumptions, challenging conventional social structures, and engaging in social action" (Crotty, 1998, p. 157). I am not approaching this study looking for inequities in power, as is typical for critical inquiry. What I am looking for is evidence that the changes introduced into the classroom with the use of clickers are consistent with the goals of critical inquiry.

Blumer (1969, as quoted in Crotty, 1998, p. 72) lists three basic interactionist assumptions:

- 'that human beings act toward things on the basis of the meanings that these things have for them';
- 'that the meaning of such things is derived from, and arises out of, the social interaction that one has with one's fellow';
- 'that these meanings are handled in, and modified through, an interpretive process used by the person in dealing with the things he encounters.'

Symbolic interactionism is necessary in order to understand the experience lived and meaning derived from each student's participation in the chemistry classroom, particularly as it pertains to how clickers are being used in that classroom on a particular day. The time spent with these students was necessary in order to understand their contextual understanding of the classroom.

As epistemology influences theoretical perspective, likewise theoretical perspective influences methodology. Grounded theory informed my methodology, which is common for symbolic interactionism. Meriam (1998) states that "The end results of [grounded theory] is a theory that emerges from…the data" (p. 17). The major challenge of performing a grounded theory is in setting aside "theoretical ideas or notions so that the analytical, substantive theory can emerge" (Cresswell, 2007, p. 65). This process is a particular challenge in this study, as previous notions on both the benefits of clickers and field dependence/field independence have already been established in this literature review. At some level, these may be considered an initial data source, and care must be taken in gathering further data not to constrain new findings to fit this pre-existing mold. The setting aside of prevailing theories is a challenge faced in all grounded studies to some extent in the search for saturation.

Two of the major techniques associated with grounded theory are open coding and the constant comparative method. In open coding, the researcher codes "the data for its major categories of information" (Cresswell, 2007, p. 64). The generation of grounded theory is generally performed iteratively by way of the constant comparative method. Which Cresswell (2007) calls "[The] process of taking information from data collection and comparing it to emerging categories" (p. 64). So once the initial coding is done, additional data should be collected to see if it is consistent with the initial categories. Ideally this would be done until saturation occurs (that is, no more categories emerge).

Other types of coding often employed in grounded theory are axial coding and selective coding. In axial coding, the researcher "identifies one open coding category to

focus on…and then goes back to the data and create categories around this core phenomenon" (Cresswell, 2007, p. 64). Selective coding is often the final step of grounded theory. In selective coding, "the researcher takes the model and develops [hypotheses] that interrelate the categories in the model or assembles a story that describes the interrelationship of categories in the model" (Cresswell, 2007, p. 65). Both axial and selective coding were used to focus on the emergent themes which provided the most promising data, developing a grounded theory to help better understand the sorts of interactions occurring in the large enrollment clicker classrooms under consideration.

A number of research methods are appropriate for approaching this study. The research questions about student perceptions can more fully be understood in context if there is a fully developed understanding of the learning environment. So it is important to investigate the professor's perspectives as well.

Purposeful sampling was used to select professors to observe and interview (Merriam, 1998). "Information-rich cases are those from which one can learn a great deal about issues of central importance to the purpose of the research, thus the term *purposeful* sampling" (Patton, 1990, p. 169, as quoted in Merriam, 1998, emphasis in original). This is in contrast to the random sampling methods typically valued in quantitative studies. When performing an observation, one must "see things firsthand and [use] his or her own knowledge and expertise in interpreting what is observed rather than relying upon once-removed accounts from interviews" (Merriam, 1998, p. 96). Semi-structured interviews "allow the researcher to respond to the situation at hand, to the emerging worldview of the respondent, and to new ideas on the topic" (Merriam, 1998, p. 74).

Purposeful sampling was also used to select student participants. Data were gathered from student participants through journaling and focus groups. "Personal documents [such as journals] are a reliable source of data concerning a person's attitudes, beliefs, and view of the world. But…[are] highly subjective in that the writer is the only one to select what he or she considers important" (Merrriam, 1998, p. 116). "Focus groups are advantageous when the interaction among the interviewees will likely yield the best information, when interviewees are similar and cooperative with each other, when time to collect information is limited, and when individuals interviewed one-on-one may be hesitant to provide information" (Cresswell, 2007, p. 133). A less structured focus group is useful when the goal is to understanding participants' thinking, participants' interests are dominant, questions guide the discussion, and there is a flexible allocation of time (Morgan, 2002).

CHAPTER IV

RESULTS

Three separate studies were carried out in this investigation, and each will be discussed separately:

- statistical analysis of historical student performance.
- characterization of the learning environment and instructor experiences.
- characterization of student experiences.

Statistical analysis of historical student performance

The data for this study were received as a Microsoft EXCEL spreadsheet from CU-Boulder. It contained information for students enrolled in Chem 1111 and Chem 1131 during the years 2002/2003-2006/2007. Chem 1111 and Chem 1131 are the first and second semester of general chemistry, respectively. Enrollment in Chem 1111 ranged from 717-844 and enrollment in Chem 1131 ranged from 502-577. Chem 1111 had been taught in three separate sections, and Chem 1131 had been taught in two separate sections. A total of 3849 students were reported for Chem 1111, and 2621 students for Chem 1131. In addition to Chem 1111, separate sections of general

chemistry are taught for engineering majors, and for smaller student learning groups. These other sections were not considered in this study.

The data had been obtained by merging the chemistry department database on student grades with the IT department database on student demographics. Merging of these databases was performed entirely by CU-Boulder employees and was not part of the work of this dissertation. The merged data were obtained and included the following: student grades for three exams, the final exam, clicker points (where applicable), total points in the course, declared major, gender, ethnicity, family resources, High School GPA, years of chemistry, physics, and mathematics completed in high school, and test scores for ACTC, ACTE, ACTM, ACTR, ACTSR, SATT, SATV, and SATM. These data types are summarized in Table 2.

Table 2: Summary of the type of data contained in the database.

Type of Data	Available data for each type
Student Performance Data	Exams 1, 2, 3, Final Exam, clicker points (if applicable), and total points in the course.
Student demographic Data	Major, Gender, Ethnicity, family resources.
Student High School Data	HSGPA, years of chemistry, physics, and mathematics in high school.
Standardized Test Scores	ACTC, ACTE, ACTM, ACTR, ACTSR, SATT, SATV, SATM

Many modeling techniques were considered, and multiple linear regression (MLR) was chosen as the model to use. MLR allows for the inclusion of important continuous variables such as HSGPA and standardized test scores, and also allows for the

inclusion of categorical data via dummy coding. Because the primary concern is how students' performance changed with teaching method, an interaction term between teaching method and each of the other dependent variables was also included in the model. "Total points in the course" was assigned as the dependent variable. None of the other student performance data were used in the model because "total points in the course" was assumed to be the best indicator of overall student performance. No modeling was attempted with any other variable as the dependent variable.

These data were then revised to obtain parameters that could be fit to a multiple linear regression (MLR) model. The following data needed to be modified somewhat before they were ready to use in the model: student major, completion of high school coursework, financial aid status, and standardized test scores.

Students enrolled in the course listed several different majors. To obtain a workable model for use in MLR, these had to be condensed into a smaller number. This was done by grouping majors based partly on similarity and partly on frequency. The most common majors were biology and psychology. More students were molecular, cellular, and developmental biology (MCDB) majors than any other major: this major was given its own category. Other biology-related majors were grouped into a category called "other biology," this category included general biology, ecology and evolutionary biology, kinesiology, and integrative physiology. Chemistry and psychology majors were given their own categories because of the relatively high number of students in each. Physics, mathematics, and engineering majors (PME) were combined into one group, in part because these disciplines often tend to rely on learning via algorithms. A separate general chemistry course is available for engineering majors; however, some

engineering majors had enrolled in Chem 1111. Other sciences (such as astronomy, environmental science, geology, and geography) were grouped into the "other science" category. Any other majors were grouped into the "other" category, and undecided students had their own category.

Figure 1 shows the major distribution for Chem 1111, and figure 2 shows the major distribution for Chem 1131. As can be seen, most students in CHEM 1111 are either undecided or biology majors, with all other categories making up 25-45% of the total each year. More students appear to have made up their minds by the time they enrolled in Chem 1131, as the number of undecided students is below 15% in each year. However, the majority are still biology majors, with total biology majors never dropping below 50% for any of the years investigated. Of the other majors, only chemistry in 2006 had an enrollment of more than 10% of the class.

Much of the data on high school completion of chemistry, physics, and mathematics were missing, although the high school GPA (HSGPA) data were relatively complete. Additionally, these data indicated only the number of years of mathematics taken in high school, not the level of mathematics. The database indicated that missing data represented a transfer student. It was decided that the best way of handling the completion of various high school disciplines was to code the student as a transfer student if all of these data were missing and as a nontransfer student if they were all present.

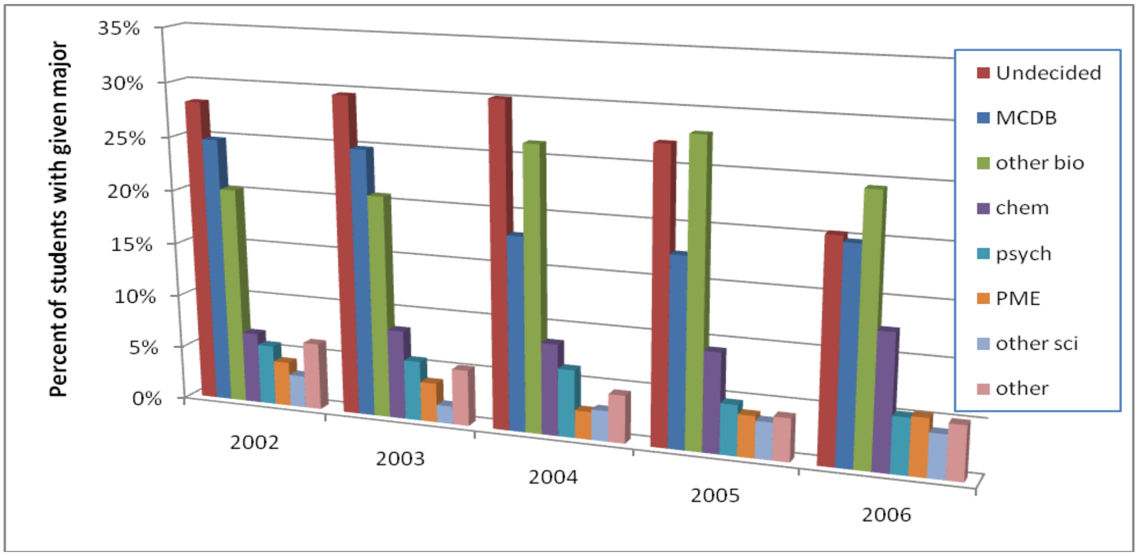

Figure 1: Distribution of student majors enrolled in first semester general chemistry for the 5 years in which data were collected.

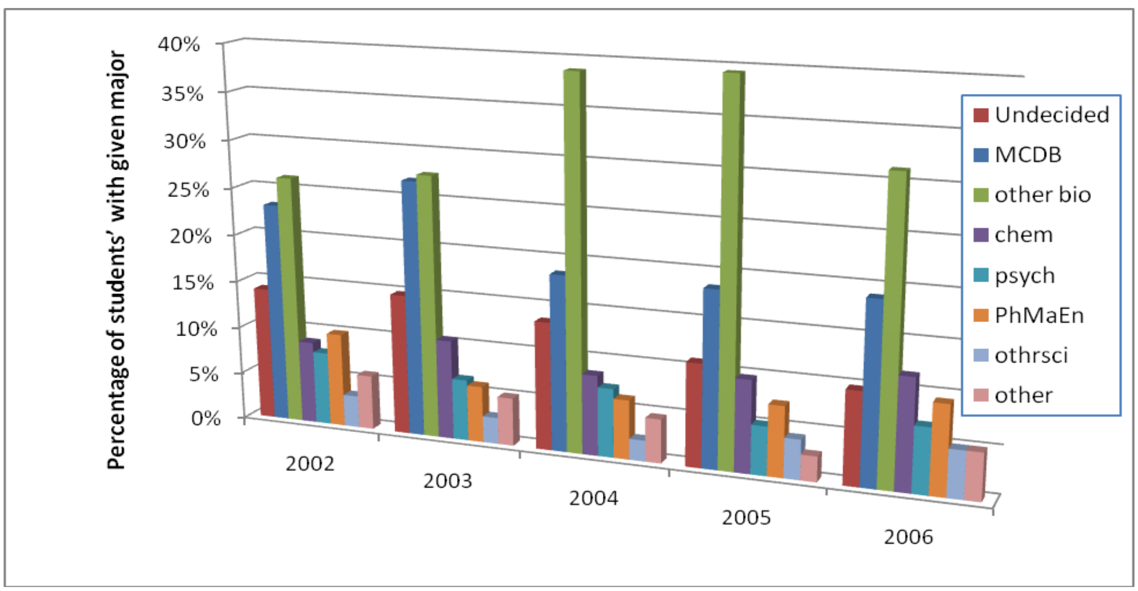

Figure 2: distribution of student majors enrolled in second semester general chemistry for the 5 years in which data were collected.

The family resources data were obtained from information on students' financial aid. The database reported quartiles of financial aid level received: students receiving the most financial aid were given a score of 1 and those receiving the least given a score of 4. Those students who did not receive financial aid received a score of 5. This category was recoded as simply receiving financial aid or not, so as to minimize the number of dummy coded variables.

Some students had taken the SAT, some had taken the ACT, and some had taken both. In order to have only one measure for standardized test scores, the ACT scores were converted to SAT scores using an equation from the university's website (McClelland, 2005). Once this concordance was performed, it was checked by comparing the SAT average of those students who had taken both ACT and SAT with the SAT score obtained by converting their ACT score to an SAT score. The number of students taking both ACT and SAT ranged from 334-401 for the five years of Chem1111 data under consideration. The result of this comparison for mathematics scores is contained in Table 3. The difference between the concorded SAT scores and the actual SAT scores ranged from -4.0 to 6.4 for the years under consideration. This difference was small enough that the concorded SAT scores were taken as acceptable for use in the model. Concordances on other standardized tests (verbal and composite or total) were also checked, but are not included in this report as they were later dropped from the model for other purposes.

A summary of simple statistics of student demographics is contained in Table 4. Student enrollment decreased for the second semester. First semester courses were evenly split according to gender, though second semester had more female students than

male students. More transfer students were present in the second semester than the first semester. Both semesters had a very low enrollment of minority students.

Table 3: Concordance of mathematics scores from ACT to SAT, and checking this concordance against those who took both exams.

Year	SATavg	ACTavg	SAT conc.	conc. Dif.	Students taking both
2002	595	25.3	580.3	4.5	376
2003	594	25.5	583.2	6.4	401
2004	588	25.2	577.7	6.1	361
2005	598	25.5	582.9	3.9	334
2006	604	25.5	583.3	-4.0	336

Table 4: Summary of simple statistics of student demographics for five years of general chemistry.

1st Semester (range for the five years)	2nd Semester (range for the five years)
Enrollment: 717-844	Enrollment: 502-577
49.7-52.9% Female	52.0%-56.4% Female
11.8-15.9% Transfer	13.0-20.6% Transfer
47-58% Received Financial Aid	45-57% Received Financial Aid
70-78% White	72-78% White

A few additional analyses were performed on the data before testing the model. The missing data were checked for any trends. The missing high school data had been used to code students as transfer students or not, and ranged from 12-16% in the first

semester, and 13-21% in the second semester. Other missing data occurred about 2-3% of the time. An independent sample t-test was used to check if there was any trend in these missing data or if they were randomly missing data. As shown in Table 5, the data were missing randomly, and could be deleted without affecting the model.

The data were also checked for multicollinearity. The only excessively high correlation occurred between standardized mathematics scores and total standardized scores. Each year had a correlation between these two of at least 0.71. Because the mathematics score was the most highly correlated with the dependent variable "total points in the course," the total standardized score was removed from the model.

Table 5: Independent sample t-test for determining if there was a trend in whether missing data were missing at random.

	t-test for Equality of Means						
Assumption of equal variance	t	df	Sig.(2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
assumed	-1.5	3846	.136	-14.7081	9.85325	-34.03	4.6100
not assumed	-1.2	337.173	.223	-14.7081	12.0446	-38.40	8.9839

After preparing the data for analysis, the model used to analyze it was:

$Gr = Cl_3 + f + Cl*f$

where Cl represents the teaching method used, f is a combination of other variables as detailed below, and Cl*f represents the interaction term between the teaching method and each of the other variables. There were three teaching methods: not using clickers, using

clickers with a traditional focus, and using clickers with a focus on the molecular level. The baseline chosen was using clickers with a traditional focus, as this teaching method had been used for the longest period of time for which data had been obtained (3 years versus 1 for each of the other teaching methods). So the teaching method was dummy coded as two options: teaching without clickers and teaching with clickers and a focus on the molecular level.

The other variables combined in the f term are summarized in the equation:

$$f=M_8 + E_7 + G + F + Tr + MT + VT + GPA$$

where M represents major (with 8 categories) and is dummy-coded with the categories listed above, with undecided used as the baseline. E represents ethnicity (with 7 categories) and is dummy-coded with the categories of Asian, Black, Hispanic, Native American, Unknown, and International. White (>70% of the population for each year) is used as the baseline for ethnicity. G represents gender, F represents financial resources (financial aid or not), Tr represents whether or not the subject is a transfer student, MT and VT represent standardized Mathematics and Verbal scores, respectively, and GPA represents HSGPA. The overall model had 68 total variables before nonsignificant variables were removed.

Because this is not an experiment, we cannot actually answer the question "which students do clickers benefit the most?" What we can do is gain some insight that will be helpful in performing further research. The professors at this university strongly believe that they are teaching much better with clickers than they were before they began to teach with clickers. It would be unethical to ask them to teach with an inferior method simply to prove a point, which is what is required to perform an experiment.

The results of the analysis are summarized in Tables 6 and 7. These tables include only the significant portions of the model. Variables which were not significant have been removed from the model unless they are dummy-coded categorical variables for which other categories are significant, or for which the interaction term with the variable proved to be significant. Any such variables were left in the model but not recorded in the tables. It should be noted that HSGPA and standardized mathematics scores represent the only continuous variables that occur in these data, and that standardized coefficients are reported for each of these.

Table 6: Significant predictors from the MLR model for the first semester of general chemistry. Standardized coefficients are reported for continuous variables.

Parameter	Coefficient/Standardized Coefficent	alpha
No Clickers	34.82	0.0024
Molecular focus	27.07	0.035
Biology majors	17.56	0.035
PME majors	37.98	0.041
Black students	-48.65	0.015
Hispanic students	-22.01	0.025
Transfer students	-27.16	0.002
Std. Mathematics Score	33.64	<0.0001
HSGPA	56.41	<0.0001
Interaction terms		
No Clickers *psychology majors	80.60	0.005
Molecular focus*PME majors	-79.34	0.0137

Note: PME = Physics, Math, and Engineering.

Table 7: Significant predictors from the MLR model for the second semester of general chemistry. Standardized coefficients are reported for continuous variables.

Parameter	Coefficient /Standardized Coefficient	alpha
No Clickers	134.05	0.0015
Molecular focus	122.44	<0.0001
Std. Mathematics Score	14.12	<0.0001
HSGPA	36.24	<0.0001
Interaction terms		
No Clickers *psychology majors	60.39	0.0444
No Clickers*Transfer students	-50.86	0.0125
No Clickers *international	-241.94	0.0137

A number of significant interactions emerged for the first semester of general chemistry. Courses taught without clickers and those taught with clickers and a focus on the molecular level both had a slightly higher average than those taught with clickers and a traditional focus. Biology and physics, mathematics, and engineering (PME) majors tended to do slightly better in the course than students who had not declared a major, while transfer students and some minorities tended to do slightly worse. Standardized mathematics scores and high school GPA were highly predictive of success. The interaction terms which proved to be significant were psychology majors doing much better than students who had not declared a major when clickers were not used and PME majors doing much worse than students who had not declared a major when clickers were used with a focus on the molecular level.

There were fewer significant interactions in the second semester of general chemistry. Courses taught without clickers and courses taught with clickers and a focus on the molecular level again both had a higher average than those taught with clickers and a traditional focus. Standardized mathematics scores and high school GPA were again predictive of success, though not quite as dramatically as they were in first semester. The interaction terms which proved to be significant were psychology majors again performing better than students who had not declared a major in a course without clickers, and transfer students and international students performing worse in a course without clickers compared to the performance of such students when clickers were used (much worse in the case of the international students).

Characterization of the Learning Environment and Instructor Experiences

It was a Friday in November, and Vince arrived early for his 10:00 AM freshman chemistry course. Like many freshman level courses, it was held in a large lecture hall with stadium seating. This lecture hall wasn't quite so large and impersonal as some of the others, however. The seats wrapped around to form almost a semicircle. Although the room had a capacity of 200 students, the rows went only eight deep, and each row was raised above the one in front of it just enough so that the instructor could see the eyes of all the students. It was almost like a fishbowl, with the instructor as the goldfish, placidly writing notes on an overhead projector close enough to the students to connect with all their little faces smooshed against the glass. There were two entrances at the

base of the fishbowl where lab personnel could wheel in chemical demonstrations and professors could sneak out and make it to their next class in the adjacent room without wading through the throngs of students. The students entered through the two entrances at the top of the fishbowl: mirrored to the left and right, each entrance opened onto a small platform area to accommodate wheelchair bound students before a short stairway descending about two feet led to another small platform and the aisle descending through the fishbowl to the base where the professor was preparing for the day's lecture. A series of announcements was already displayed on the overhead above.

The seats in the fishbowl were mainly vacant, but Vince took a seat on the floor towards the back of the classroom. It was almost as if he were sitting on the rim of the fishbowl, not quite ready to dip his feet into the water. Vince had stringy blonde hair that hung to his shoulders and a scraggly goatee. He wore black fingernail polish and a Motley Crue T-shirt. He took out his notebook and prepared for the beginning of class.

More students began filing in, filling up the seats at the back of the fishbowl and eventually plopping on the floor around Vince and in the wheelchair accommodation area behind him. None of the students needed the accommodations, but some of them hadn't come to class with a notebook like Vince had, and some appeared in need of sleep. Later in the class that day, the professor would inform the half dozen or so students arranged on the floor and tables in the area behind the seats that there were a lot of good seats down in the front. "It's more comfortable back here," one of the students would reply while adjusting her seat on the hard floor, though perhaps not quite loud enough to be heard by the professor in front.

Within five minutes of the start of class, a multiple choice question was displayed on the screen and the students were hard at work trying to find the answer: “What is the formal charge of oxygen in ClO_2^-?” As the professor bantered about the weather, students slowly began to discuss how to go about answering the question: “Oxygens are full it looks like”, “How many lone pairs on Chlorine?”, “You need to…” Every once in a while a student presses a button on a small white device about the size of an iPod and sits back in their seat with a look of contentment. After they’d been working on the problem for three minutes, the professor gave them a hint to look for atoms which could have an extended octet. Right about then, Brittany and Crystal walk into the classroom with the air of confidence possessed by students who know there are much more important things in college than showing up to class on time.

“Oh, a clicker question,” says Brittany.

They look around for a vacant seat, but there aren’t any near the back, so they plop down in the crowded stairway with Vince and the others.

Four and a half minutes have gone by since the question was first displayed, and the professor says to the class “We can’t spend all day on this one,” before going to help a student in the front row.

Vince turns to Brittany and says “I got zero, is that right?”

Brittany is feverishly trying to catch up as time runs out. They compare notes, and select their answers with the white iPod-looking devices: clickers.

The professor has finished helping the student in the front row and says “That’s way more time than I said I’d give you. How about five more seconds?”

The last remaining students select their answers, as the professor stops the voting. A histogram displays the results: five minutes and thirty-five seconds spent on the question, 135 students voted, 69% got the correct answer of zero. Presumably Vince was among them.

The professor tells the class that if they practice at home they will be able to answer the questions faster, and then she begins to work through the problem, showing them how to arrive at the correct answer.

Characterizing courses and summary of data collected.

I observed four professors (three female and one male) teaching various levels of chemistry courses at CU-Boulder. These professors were assigned the following pseudonyms: Dr. Joule, Dr. Thompson, Dr. Kelvin and Dr. Gibbs. Dr. Joule and Dr. Gibbs had each taught both a large enrollment freshman chemistry course and a small enrollment physical chemistry course with clickers. Dr. Kelvin had taught large enrollment courses in freshman chemistry and organic chemistry with clickers. Dr. Thompson had taught only the freshman level course with clickers, but also had two years experience teaching chemistry in high school. The number of observations per professor varied from two to seven. During these observations, I took notes on the setting, interactions between the professor and the students, interactions among the students, details of clicker questions, any interactions between myself and students, and my own feelings about making the observations (Merriam, 1998). A summary of some of the details from the observation and interviewing of each professor is provided in table 8.

Table 8: Data collected during the observation and interview of professors.

Professor	Courses observed	Size of course.	Words in Observation Notes	Words from transcriptions and field notes from interviews
Joule	1st semester General chemistry	140-300	1,320	2,518*
Thompson	1st semester General chemistry	140-300	2,193	8,294
Gibbs	Physical chemistry	30	503	940†
Kelvin	2nd semester General chemistry, Organic chemistry	200-250	Not included	4,591

* Much of interview data are missing due to technical difficulties.
† Entirely based on field notes, as technical difficulties prevented recording.

Professors Joule and Thompson were team teaching all three sections of general chemistry. Dr. Joule taught all three courses for the first five weeks of the semester, and Dr. Thompson taught all three courses for the last ten weeks of the semester. Student population in these sections varied from 140 to 300. Two different classrooms were used for these three sections, and when I observed there might be differences in the classroom environment based on the room it took place in, I made an effort to look for these differences. I observed the same lecture in both classrooms twice for each professor in order to look for differences.

Professor Gibbs was observed teaching an upper level physical chemistry course with an enrollment of thirty students. Professor Kelvin was observed teaching the second

semester of general chemistry with 200-250 students attending class and a first semester organic chemistry course of about the same enrollment.

I also interviewed each of these professors. The interview consisted of an email interview followed by a 40-50 minute in-person interview. The email interview contained several general questions about how long they have used clickers, how often they use them, and what they view as advantages and disadvantages. The in-person interview was semi-structured, and was designed for each professor individually based on their responses to the email survey, observations made in their classes, and in some cases interesting responses made by other professors in previous interviews (Merriam, 1998). Before conducting the interviews, a list of possible questions was generated and critiqued by the UNC chemical education research group. I modified the questions based on this feedback. I audio recorded and later transcribed all interviews myself, but there were some technical difficulties: in the interview with Dr. Gibbs, I was not able to record any information and had to rely entirely on field notes, in the interview with Dr. Joule, the batteries died approximately halfway through, so I had to rely on field notes for the second half, and the interview with Dr. Thompson went rather long so the recording device missed the last few minutes of the interview. There were 20,359 words of data collected during the observations and interviews, as summarized in table 8.

Data Analysis

The observations and interviews revealed some similarities between the use of clickers by the instructors as well as a number of differences. The data from observations

and interviews were integrated into the findings to give a more complete picture of how the clickers were used by these professors.

After interviewing Dr. Joule, Dr. Thompson, and Dr. Gibbs, I analyzed the observation and interview data using open coding to find important themes common to all of them. The interview with Dr. Kelvin did not occur until after this analysis had been made because of difficulty with scheduling this interview relative to deadlines regarding a report on the material from this interview. I used this situation as an opportunity to use the constant comparative method (Cresswell, 2007). The transcription of Dr. Kelvin's interview was compared to the themes already found in the other interviews. I did not transcribe the observation notes made in Dr. Kelvin's class during this process, and so the number of words of data from observing Dr. Kelvin's classes was not included in Table 8.

There were differences in the manner in which the professors started using clickers. Dr. Joule said that when she began using clickers, it was a very natural implementation, whereas Dr. Gibbs said it was rather ineffective the first time that he used clickers and that it took three years and a deliberate effort to become more effective. Dr. Kelvin said that the timing of introducing clickers with team teaching was "definitely a positive thing" because the professors involved were spending a lot of time talking about goals for the course and how to write questions.

There were a variety of responses when professors were asked what advice they would give to novice instructors. Dr. Kelvin said:

> I think having some kind of a network. Team teaching, working with other faculty, can be a huge plus when you're trying to develop questions…There is so much information out there to be able to get

> questions that other people have used. Use them in your own classes and then tailor it to the unique needs of your students.

Dr. Thompson says "My biggest piece of advice would be not to force it," whereas Dr. Gibbs would advise novice clicker users to read published reports from professors who have used clickers and observe other professors using them first. On the face of things, these may appear to be contradictory messages; however some of the differences may be due to the goals each professor had for using clickers as well as differences in their teaching styles. Reconciliation of these apparent differences will be discussed in chapter V.

I observed differences in the styles of administering the clicker questions among all four instructors. These differences are summarized in Table 9, and detailed in the following paragraphs.

Table 9: General observations of professors.

Professor	Courses observed	Typical number of questions per class period	Grading of clicker questions.	Relation to material.	Behavior after soliciting clicker responses.
Joule	General chemistry	2-4	1 for answer, 2 for correct, ~5%	Just after covering.	Show historgram with correct answers displayed, discuss why it was correct.
Thompson	General chemistry	2-3	1 for answer, 2 for correct, ~5%	Just after covering.	Show historgram with correct answers displayed, discuss why it was correct.
Gibbs	Physical chemistry	1-3	Not graded.	Often new concepts.	Use clicker questions to initiate class discussion. Reveal answer at the end of this discussion.
Joule	General chemistry, Organic chemistry	1-3	1 for answer, 2 for correct, ~5%	Not as similar to previous examples, but not completely new.	Discuss question with class before revealing histogram.

Dr. Joule tended to have two or three short questions in a row just after covering the material. Dr. Thompson would also tend to have questions just after covering the material, but typically had fewer questions and allowed more time for students to work on them. Both Dr. Joule and Dr. Thompson would typically display the histogram of student responses, show which selection was correct, then explain why that was the

correct answer. On one occasion, Dr. Thompson did not go over how to arrive at the correct answer, as the next question built on this question. She did, however, display the histogram and correct choice, and told students if they had selected differently they needed to go back and look at how they did it before proceeding with the follow-up question. Dr. Joule did not tend to interact with the students while they were answering the clicker questions, while Dr. Thompson almost always initiated interactions between herself and the students during this time: either off-topic banter (about baseball, the weather, upcoming holidays or the weekend), providing hints midway through the question, or answering student questions from the front row. She would almost always negotiate with the students about how much time they had left.

Dr. Gibbs would typically watch his laptop screen as students were working on the question, presumably to see how well they were doing based on the histogram displayed there. He didn't typically display the histogram when the time for answering the questions had expired. Instead of telling the students the correct answer, Dr. Gibbs had student volunteers provide a reasoning for their selection, usually having students who had picked different answers put forth their reasoning. The clicker question itself served as the beginning of a class discussion that often would last ten minutes or more. Only at the end of this time was the correct answer revealed. Dr. Gibbs on one occasion had two related questions, and actually went back to the first question after students answered the second question (presumably because thinking about the way they answered the second question might affect how they would think about selecting their answer to the first question). In the interview with Dr. Gibbs, he confirmed that he used this same approach in large enrollment lecture classes, claiming that the full class

discussion is extremely important because students might choose the right answer for the wrong reason, and that it shifted the focus to understanding the right answer.

Dr. Kelvin tended to ask fewer clicker questions during the class. Questions would vary in the time allowed: some were conceptual questions with around a minute to answer, while some were algorithmic with several minutes. On questions with longer time periods, Dr. Kelvin would walk up and down the aisles, sometimes stopping to answer student questions. Dr. Kelvin typically discussed the question before revealing the histogram with the correct answer. Dr. Kelvin often used the Socratic method to elicit student responses in arriving at the correct answer, but this didn't turn into a class discussion as in Dr. Gibbs' physical chemistry course, where students would put forth competing ideas and then try to explain them. These differences are likely due to several factors: the professor's preferred teaching method, the number of students in the course, and the level of the course.

Not only the style of implementation, but the difficulty level of the questions varied between the courses as well. This was due not only to Dr. Gibbs' course being a senior level versus a freshman level course, but also had something to do with the way in which questions were selected. Most of the questions Dr. Gibbs posed to his physical chemistry students were based on material that had not yet been explicitly covered, while in their general chemistry classes Dr. Joule and Dr. Thompson almost exclusively asked questions based on material already covered, often just prior to asking the question. Dr. Kelvin had a mix of questions over material covered and conceptual questions that were not on material that was explicitly covered. In one case, Dr. Thompson asked for volunteers from the class to predict a phenomenon that had not yet been discussed (the

location of the lone pairs in a molecule with sp^3d geometry). This seemed like the type of question Dr. Gibbs might ask his students with clickers, as students might be able to come to the right conclusion based on an understanding of electron repulsion. But in this case, Dr. Thompson chose not to use clickers to elicit student responses. I didn't notice any difference in difficulty between the questions Dr. Joule asked and those Dr. Thompson asked based on the histograms that I observed or the type of material in the questions relative to the information already covered in the class. They were always questions based on material already covered in class, and students often had access to an algorithm to arrive at the correct answer (although this was not always the expected way of arriving at the correct answer). Students answered clicker questions correctly less often in Dr. Kelvin's and Dr. Gibb's courses, where the questions might not always be as explicitly related to material already covered.

In the interviews, I mentioned question categorization schemes used by some chemistry educators (Towns, *et al.*, 2007; Murphy & Knauss, 2008; Mundell & Ferguson, 2008) and asked if they thought about this when they wrote questions. Dr. Gibbs says he was not that systematic, but did informally try to push to a higher level. He does mention that his method is modeled on the one developed by Eric Mazur (Mazur, 1997; Crouch & Mazur, 2001), which relies heavily on questions about intuitive concepts, often before they are covered in class. Dr. Thompson describes the type of question she uses in class as:

> The first one of the day is almost always review. And then occasionally you have regurgitation…where they're just: "Ok did you hear what I just said." And then I think sometimes I'm able to put some together that I'll consider you know… synthesis of different topics.

Dr. Kelvin says:

> You try to avoid pure recall questions. You're more interested in if I give them all of this information how do they put this information together: to synthesize these ideas and process the information to get to where I want them to be. So I think their higher level thinking skills are being challenged. And also I use my questions to reinforce concepts.

She further adds, "The first time you write questions you really quickly realize you have a tendency to write more recall type questions and not really questions that challenge critical thinking skills or that synthesize ideas. And so you grow through those experiences." These descriptions are consistent with what was observed in their classes.

Some of the professors addressed the effect clickers seemed to have on student performance. Dr. Gibbs says that since using clickers he has seen students that might have otherwise gotten Cs in the course get Bs in the course. This matches the claims made by Mazur regarding the usefulness of clickers (2001). Dr. Thompson, on the other hand, says:

> I don't think that the net result—their final performance on exams for the class as a whole—is all that much different. I think they probably are getting the concepts a little better: they're leaving class knowing it a little better. So they're probably relying on their textbook or their notes or something a little less than if they weren't using the clickers…So I don't know. It's hard to say. But I don't think it changes the bottom line.

Draper (2004) noted that clickers are best used when the appropriate niche is found, and that the focus should be on the pedagogy, not the technology. This mirrors Dr. Thompson's comments regarding "not forcing it" and also leaves room for the more deliberate approach of Dr. Gibbs or that employed by Mazur.

The most commonly mentioned reasons for using clickers in anecdotal publications are formative assessment and promoting student collaboration (MacArthur & Jones, 2008). Both of these reasons emerged in the interviews with the professors.

Regarding formative assessment, Dr. Thompson said, "I do like it, because then we do get feedback. And even the most timid of students, you can see if they got it wrong…It's when you get 50/50, no clear cut winner that you [decide you should] go over that better. But that's really good feedback to have, too, for them and for me." Regarding student collaboration, Dr. Kelvin said:

> When we start using clickers all of a sudden the instructor's voice is silent. And then you hear the students engage with one another. And I think in chemistry the processing of information is so much more important than just picking the right answer. And I think that students through these kinds of discussions began to see the effect of …working with their peers and of focusing more on the process than simply getting the answer.

but went on to caution:

> Collaboration is a good thing, but often there are students who are not doing any thinking on their own: they're getting all the response from their neighbors and so they accumulate all these points and they think they understand it. And on an exam they are all on their own. They have no crutches. No textbook. No notes. And in those situations students who do poorly get quite frustrated and upset.

The amount of student interaction during clicker questions seemed to vary based on course size. In every observation, most students interacted with each other in Dr. Joule's, Dr. Thompson's and Dr. Kelvin's classes during the clicker questions. These interactions were either actively encouraged or accepted by the professors of the course. Students would sometimes work individually before they began interacting, but I did not notice any obvious trends regarding this behavior. In Dr. Gibb's physical chemistry course (with an enrollment of 30), the students did not tend to interact with each other during clicker questions. In most cases, they answered individually. In only one case did there appear to be some student interaction, based on a very low murmur. In my interview with Dr. Gibbs, he confirmed that this difference is due to the size of the class,

saying there was “no spontaneous breaking into talking” in smaller classes, whereas he said this did occur when he taught the large enrollment course.

All three professors addressed issues of course size in their interviews. When asked in which course they would use clickers if they could use them in only one course, all four professors chose the largest enrollment course. Dr. Joule said:

> I guess the large general chemistry course. I see the clickers there as almost essential to keep the class engaged. Before I used clickers teaching in that large classroom…the dynamic was totally different. I mean you’d look around the room and students would be reading the newspapers, sleeping, and there were always pockets of students who were talking. And we have found that using clickers here the students are engaged. They’re paying attention. They know a clicker question might be coming up. And so I find it all so much more rewarding. I feel that I am really communicating with the class. And they are communicating back.

Dr. Thompson said “If I could only use it in one I’d use it in the big room. I figure in the smaller room we could probably come up with something to make sense of it.”

Most of the professors indicated that even with clickers, courses could be improved by having more sections and smaller course sizes. Dr. Joule said:

> And I think one of the things that [the University] could do right now to improve general chemistry is to have smaller class sizes. If we had more instructors and I could teach a class of 100 students at a time, and teach two or three of them it would allow, again, more questions. More interaction. So I wish that were possible.

Dr Gibbs indicated that nothing could be done for courses with an enrollment greater than 200, and he would recommend having smaller courses. Dr. Kelvin said “I think with the large classroom the instructor feels helpless. You try to engage the students as best you can, but at some point you have limitation.”

An interesting theme I observed that I hadn’t originally considered was the effect of the classroom. General chemistry courses were meeting in two separate classrooms: one with a capacity of 200 arranged in a semicircle, which had the effect of making it feel

smaller (the fishbowl), and one with a capacity of 500 that had a very impersonal feel to it. I found the larger classroom much more conducive to being a nonintrusive observer: I would often sit on the floor in the very back to promote nonintrusiveness in this classroom, but eventually moved back to sitting in one of the seats, as the floor in back tended to be a popular place for many students to sit. I felt more intrusive arriving before the class in the smaller room started than I felt arriving late for classes in the larger classroom. In Dr. Joule's lectures, there were often more questions from the students in the smaller classroom (~140 students) than there were from students in the larger classroom (~300 students). Dr. Thompson's lectures had more questions in general, but they were more balanced, with the smaller classroom having a similar number of questions to the larger classroom. In the larger classroom, Dr. Thompson might have students with questions from anywhere in the room, whereas Dr. Joule typically had student questions only from the very front.

The professors were aware of this difference as well. When asked about the difference, Dr. Joule said "When I attend [the fishbowl], I can actually see the eyes of all the students, even in the back. Whereas that is not true [in the other classroom]. It's much more personal in [the fishbowl]. It's interesting that you could sense that." Dr. Thompson also noted the difference between the two rooms:

> [The fishbowl] is small enough that say, for instance, I was one day messing with one of the TA's and he blurted out the answer. Well everybody hears it in [the fishbowl], so the question is ruined. But in the bigger room…anything can happen in the back and I'm not going to even know it. And I like it in the big classrooms, because, you know, in a smaller classroom I can pretty much see what everybody's doing. But in the big classroom I can't see what half of them are doing in the back. So it is nice in that they're engaged more than they would be otherwise. But that's probably true in both rooms a little bit.

Although not teaching in the fishbowl during the observation, Dr. Kelvin had taught there before and commented on the difference as well:

> For one thing I think [the fishbowl] is much more of a friendly atmosphere because I think all of the students feel that they can make eye contact with the instructor and there is more accountability in the interactions. In the large lecture it is almost like fifty percent of the students think that the instructor can't see them. It doesn't matter what they do: whether they are looking at something on the internet, whether they are reading a newspaper. And you only find that the first half of the class is actively engaged with you.

So the effect of course size appears to be limited not only to the difference between small and large courses, but between large and very large courses as well. Though most professors would prefer not to have classrooms with more than 200 students, clickers appear to make such classes much more tractable if such sizes are necessary.

A theme that emerged particular to the situation of Dr. Joule and Dr. Thompson was the logistics of teaching three simultaneous sections of the same large enrollment course. Both professors referred to the experience as somewhat of a performance. Dr. Joule says "…with a huge class I sometimes think it's almost more like a show (laughs) you know where I know exactly how much time each thing is going to take," and Dr. Thompson says "It's hard to stay up the third performance of the day."

There appear to be a few implications related to teaching three simultaneous sections of the same course; one of these is instructor breaks. Dr. Joule continues to say "…and to do that without interruption for 50 minutes, is very tiring for an instructor. So having these breaks is also helpful for keeping up my energy level. So I find clickers right now almost indispensable for these large lecture courses." Dr. Thompson said "So…sometimes they need a little break from listening to my voice. Sometimes my voice needs a little break," and when specifically asked about the importance of having

an "opportunity to fidget," Dr. Thompson replied "Well, not so much. I mean, right now because I'm teaching three sections it is nice to have a little break. But less critical."

The logistics of teaching three simultaneous courses could also have a profound effect on the way in which questions from the class are handled. Dr. Joule says:

> And I might add, actually, one other constraint that we have in teaching these large courses is, since I do three sections, it's relatively critical that we can cover the same material in each hour. And occasionally we will get behind and get ahead, and that makes it very difficult for the next class to start at a different point. So in these large classes, I will almost discourage questions. Because I try to really fill my time very efficiently.

When asked to elaborate on this, Dr. Joule responded: "But if I were to try to entertain too many questions then one section may have more than another." In light of this response, Dr. Thompson was asked if it was a concern that they not get through the material if there were more student questions, and she responded "I mean, certainly that's in the back of my mind… But…I try to let them ask questions because it's good for their development if they're thinking it." And further added "I like it because at least it means they're paying attention. If I go a whole fifty minute class period to a room of blank faces…everybody could just be spacing out. At least if they're asking questions I know a few people are paying attention." These responses are consistent with the differences I observed in the frequency of questions from the class in their respective classrooms.

Dr. Joule and Dr. Thompson had different ideas about how clickers related to student attendance. Although both believed that using clickers increased attendance, Dr. Joule thought this was a good thing, whereas Dr. Thompson viewed it as a negative. A few times in the interview, Dr. Joule mentioned the increased attendance as a positive aspect of using clickers: "So I find that the large classes, using clickers encourages attendance a bit more," and later adds, "So they try to come to class, but often don't quite

make it unless…they see it as very important in getting a few points for their grade. Something that will entice them." Dr. Thompson felt differently about this:

> There are kids who come to class just for the clickers. I don't like that. Because if they don't want to be there I don't want them to be there. Because for every kid who's there who doesn't want to be there, there are two kids who do who get distracted by him or her. You know by the kid who is playing with facebook the whole class and the people behind him just can't help but "what's going on there?" So that is a negative. So if there was a way to have them and have everybody take them seriously but not come to class just for the sake of getting clicker points that would be ideal for me.

This question of clickers improving student attendance to the point of having a disruptive class has previously been investigated by another chemistry professor (King, 2008). He found that decreasing the overall percentage of the grade awarded for clicker questions was enough to keep the disruptive students from attending, but that the students who were there still took them seriously.

Dr. Joule and Dr. Thompson were in agreement that using clickers only for the purpose of taking attendance was a bad idea, as evidenced by the following statement from Dr. Thompson: "I hope the students don't think I just use them to check attendance, because there are classes where that happens. And students really…don't like that." Student responsibility was a theme connected to attendance for both professors. Dr. Thompson said "And that's what it's about at this level. Right? They should be making choices. And that's why I said that I think it forces people to come to class who don't want to be there. Because if you don't want to be there then who cares?"

One aspect of the success of clickers that emerged was having a University culture that supported and encouraged their use. Dr. Joule mentioned how helpful it was to have the support staff for the clickers. Dr. Thompson referred to the supportive culture on many occasions: "When I came here, they were in the culture. So I was sort of told

you will use them. So, alright, I'll try anything once." Based on her answer to this as well as many of the questions, Dr. Thompson seemed to be more willing to teach the same large classrooms without using clickers than the other three professors were. However, she did mention that the University culture regarding the use of clickers was very helpful for implementing them in her classes:

> I wasn't going to ask students to go out and buy another clicker. There was an era…where you could have as many as three different clickers. That's ridiculous…If I felt like it wasn't an undue burden to the students to buy this and use it and have it. Fine. But like I said it's nice here because it's part of the culture. You're not asking them to buy something that they're not going to use for another class.

Dr. Kelvin discussed a bit of how this culture evolved in the chemistry department:

> So I think for us the main reason why it ended up being quite successful is because there was a group of faculty working together to bring in innovations to actively engage students in the large classes. And this was the first time that we were able to engage the students. We were able to get student input and feedback about the pros and cons of [using] them in the classroom … you were getting feedback in real time that helped you then to integrate other components of teaching into your lecture, which completely changed the dynamics of teaching.

This "clicker culture" at the university is probably a very important part of their success.

Student Interview Results

Eleven students participated in the study, nine female students and two male students. All students who participated were Caucasian. There were four students who indicated during the interview that they had transferred from another school. All students except for Rosalind appeared to be of traditional college age. Benjamin had recently received a bachelor's degree, but appeared to be in his early to mid 20s. The participant

population differed from the enrollment in the course in that participants were more likely to be Caucasian, female, and transfer students than were the students in the course as a whole. No effort was made to control the demographics of the student participants other than to obtain more female participants in order to have same gendered focus groups, as described in Chapter III.

All students were enrolled in Chem 1111 with a classroom size of ~300 students. There were two sections of the course, one taught at 8 AM and the other taught at 11 AM. The students were not asked which of these sections they were enrolled in. Both sections were taught by Dr. Thompson.

This portion of the study was performed the year after the instructor observations were conducted. There were only two sections of the course, as opposed to three the year that the observations and instructor interviews took place. Both of these sections took place in the large enrollment classroom that the instructors had identified as being more impersonal. A separate section designed for chemistry majors was taught in "the fishbowl" by an instructor who had not been observed or interviewed the previous year. Three observations were made during this year to see if Dr. Thompson was teaching in a similar style to what she had used the year before. Her teaching style appeared to be the same, and she confirmed in an email that there were no differences between how she taught the course the year that the student interviews took place and how she taught the course the year that she was interviewed.

The hidden figure test (HFT) was scored for the 11 students who participated in the interviews. Three students had results in the range of 5-7 and were labeled field dependent. Five students had results in the range of 12-14 and were labeled intermediate.

Three students had results in the range of 18-27 and were labeled field independent. My score on the HFT was 9, indicating that I am likely moderately field dependent.

Table 10 summarizes the level of participation of each of the students who volunteered. Everyone who was asked to participate in the email portion, except for one female FI student, Edith, and one male intermediate student, Benjamin, responded to at least one of the email surveys. Of the students who responded to at least two of the three email surveys, the longest set of responses was from an FI student, Marie, while the shortest was from an FD student, Lise. Dorothy, an FI student, responded to only one of the email surveys, and had a longer than average response to it. At the time the third email survey was sent to the class, Rosalind indicated she had dropped the course for financial reasons. Anne was not asked to respond to any of the email surveys because her interview occurred after the three email surveys had been sent to the participants.

Because the largest group of students was intermediate, and the available number of students in each of the FD or FI categories was insufficient for a complete focus group, I decided to have a separate focus group for the FD and FI students, but gather additional students for each group from the intermediate students. Of the three female intermediate students, two were able to participate in the focus groups: Irene, and Mariah. This resulted in a focus group with two FD and one intermediate student, and a focus group with two FI and one intermediate student. Both focus groups consisted of only female students. One of the FD students, Rosalind, informed me that she had dropped the course, and one of the FI students, Edith, did not respond to any of the email surveys after the initial interview. The FD focus group was composed of Lise and Anne, both FD students, and Irene, an intermediate student. I received an email shortly before the start

of the FI focus from one of the participants, Dorothy, saying she was sick and unable to participate. So the FI focus group that met was composed of one FI student, Marie, and one intermediate student, Mariah.

Table 10: Demographics and level of participation of student research participants.

Pseudonym	FDI score	Major	Year	Gender	Interview length (words)	Number emails and length	Focus group
Rosalind	5/FD	Pre-pharm	Sr*(NT)	F	2,275	1†/ 228	
Lise	6/FD	Op	Soph*	F	1,632	3/212	FD
Anne	7/FD	MCDB	Fr	F	4,189	0††	FD
Irene	12/FM	Psy	Soph	F	1,958	2/279	FD
Antoine	13/FM	MCDB	Fr	M	2,599	2/442	
Mariah	14/FM	MCDB	Fr	F	2,326	2/321	FI
Benjamin	14/FM	Pre-Med	PB*	M	4,058	0	
Ruth	14/FM	MCDB	Fr	F	2,166	3/ 310	
Marie	18/FI	Iphy	Fr	F	2,316	3/ 949	FI
Dorothy	21/FI	Iphy & Psy	Soph*	F	2,701	1/246	
Edith	27/ FI	Phy	Soph	F	2,251	0	

Note: FD=field dependent, FI=field independent, FM=field intermediate, Iphy=integrative physiology, MCDB=molecular, cellular, and devevlopmental biology, Op=open option, Phy=physics, Psy=psychology, Fr=freshman, Soph=sophomore, Sr=senior, PB=post baccalaureate, NT=non traditional

*Transfer student.

†Student emailed me indicating she had withrdrawn from the course for financial reasons.

†† Interview occurred after the email portion of the study.

The two focus groups had very different moods. The students in the FD focus group were much more cooperative with each other than were the students in the FI focus group. Because there were some technical difficulties in the FD focus group, the first five minutes of the interview were not videotaped, and the following couple of minutes were not video or audiotaped. This time period corresponded to a section of the interview in which participants were asked how they felt about specific clicker questions. I relied on field notes for analysis of this discussion. Despite this missing portion of the FD focus group, the transcription of it was still about 40% longer than the transcript of the FI focus group. The transcript for the FD focus group was 9,679 words in length, while the transcript for the FI focus group was only 6,398 words in length.

The FI focus group felt much more like a set of parallel interviews than it did like a focus group. Mariah mentioned being competitive at times, and she seemed almost to be competing to answer the questions. Marie, on the other hand, seemed a bit more aloof. At times it appeared she was interested in answering something, but Mariah answered first and she no longer had a response at the end. The FI focus group seemed to suppress the amount of information from Marie instead of enhancing it. The participants very rarely interacted with each other, maybe saying something like “yeah, I would agree with that,” but not even bothering to turn to the other person while saying it. Mariah almost always looked straight ahead. Marie would sometimes turn her head halfway towards Mariah while she was talking, but never really built on what she had said. I don’t believe that the FI focus group provided more information than might have been gained from individual interviews; in fact, it may have provided less.

The FD focus group was very much an interactive focus group. Participants responded to each other's comments often, and sometimes even finished each other's sentences. Irene was very demonstrative, with lots of head nods and hand motions while she talked, often in a way to encourage others to participate more. Anne did not use hand motions as much, but would often smile at other participants while they talked and sometimes added verbal affirmation to their comments. The camera was not able to capture Lise. She was very shy (she had mentioned this in the interview) but felt comfortable enough to engage with the other students, agreeing to some things and sometimes offering alternative perspectives to those that the other students had put forward. Sometimes participants looked as though they wanted to say something while others were talking, but they usually waited and spoke when the other participant was done. I believe that I was able to gain more information from this focus group than I would have just from a series of individual interviews, based on the extent of interactions between the student participants.

The interaction between students that occurred regularly in the FD focus group is an important piece of data that will be included in the analysis. Unlike quoting an interview, there is no agreed upon method of indicating multi-personal interactions. Brackets [] will be used to enclose the name of whoever is adding to what is being said along with the action they are taking. These could represent one of the other participants' nonverbal communication, or interruption of whatever the primary speaker is saying. As an example: Lise says, "It feels like so much of your grade sometimes. [ANNE: yea] You just sometimes need those points 'cause you do bad on an exam or something,

[IRENE: nods] like you need those points. [IRENE: Sometimes it also like stresses you out more, like you have to do so well.]"

A few other conventions will be used to clarify the source of the data in the following analysis. Student opinions may have come from individual interviews, email responses, or from the focus groups. Data from email responses or focus groups will indicate the source. If the source is not indicated, it is from an individual interview. Also, a label will often accompany student quotes to help identify which category they are in: FI for field independent, FD for field dependent, and FM for intermediate.

All of the data were printed and then analyzed to find themes. The combination of interview, email and focus group data amounted to 47,535 transcribed words. Initially 33 themes emerged. Some of these themes turned out to have only a single occurrence, others later appeared to be the same theme from different vantage points, or were subthemes of a more dominant theme. Some themes appeared to be important; however, there were insufficient data to fully develop them, and significant research related to them is being done elsewhere (Towns, *et al.*, 2007). These themes had primarily to do with categorizing or characterizing the questions used. The criteria used to decide which themes to focus on were: relevance to FDI categorization, connection to important aspects of clickers mentioned in the literature, importance to professors teaching this course, congruence of data from several sources (participants), and lucidity of the data within the theme.

Some of the major themes which emerged were:

- students overall impressions of the course, clickers, and other courses in which clickers were used

- student collaboration and factors which affect it
- the types of clicker questions and how students try to solve them
- formative assessment.

Some minor themes will be discussed in a section on other themes:

- how class size affects clicker use
- technical difficulties with clickers
- the anonymous nature of clicker responses
- time management issues with the use of clickers
- how attendance relates to clickers
- concerns about the use of clickers to control student behavior.

Overall Impression and Comparison of Clickers in Chemistry to Other Courses

Student participants had an overall positive impression of the course as a whole as well as the way in which clickers were used in it. Every participant except for Edith (FI) had positive things to say about their overall impression of the course. Anne (FD) described her experience, "[I like] the way that she'll sort of take notes with us… I like that her personality comes out in the way she teaches. And it's much more easy for me to be involved and to be listening and to be paying attention, when she goes over the notes and discusses." Benjamin (FM) compared his experience in chemistry positively to that he had in a biology course:

> I like the fact that she writes things, I'm not a big fan of powerpoint presentations. I find that I don't get a whole lot out of them…my bio class is a powerpoint class, in comparison. I leave the bio class feeling like I need to reread the stuff. And then the chem. classes I go in not necessarily understanding it and come out feeling I have a really good grasp of it.

Ruth (FM) added, “And I feel that we have been moving at a pace that’s, like, good enough to understand it but not too slow that we’re wasting time.”

Students mentioned the clickers in particular as being a positive aspect of their learning experience. When asked how she felt about clickers in the interview, Mariah (FM) had a typical response saying, “I think they’re fun. I look forward to them. Until I get them wrong, then I’m like dang it!” In her interview, Marie (FI) said, “Everyone I’ve talked to [thinks] they’re a useful tool just to stay engaged.” Rosalind (FD) mentioned hearing students in one of her previous courses saying they didn’t like clickers. She said, “Well I heard a couple of times, and this was in intro chem., people just didn’t like them (laughs) they’d get frustrated with them sometimes...they didn’t like the clickers period as far as they didn’t like using them.” Although later she added, “I mean I think overall they’re a good learning tool. Definitely, because, like I said, especially if you’ve gone over the information then it just kind of lets it sink in more.” It’s possible that the way they were used in this other course affected these other students’ perceptions of them.

Edith (FI), the one student who was critical of the course, said, “In this particular class, so far, in just two weeks of class, there have been several typos in the clickers. But that’s not so much the clickers fault as much writing the clicker program.” Although she was much more critical of some of her other courses, calling one professor, “a bumbling old goof,” and overall seemed to think that clickers were useful to her learning.

Because of the institutional commitment to the use of clickers, many of the students had used clickers not just in their chemistry course, but in other courses as well. Students were asked about other courses in which they used clickers, and to make comparisons between the methods used in the different courses. Many students had used

clickers in biology, and some mentioned physics and other courses. Some of the differences which emerged between the courses had to do with different ways of eliciting student collaboration and different methods of grading. Participants indicated that the biology course differed from the chemistry course in that students were sometimes asked to answer without first collaborating in biology, and that the clicker points in biology were awarded only for participation, not for answering correctly. Differences in grading method and student collaboration, which are major themes, will be addressed more fully in the relevant sections. Two other themes emerged relative to clickers in other courses, however: courses in which clickers are ineffective, and courses in which clickers are not used.

A few students made comparisons between the courses in which they had clickers and courses that did not make use of clickers. In her interview, Anne (FD) compared her chemistry course with a 100-student history course she is also taking:

> And it's much more easy for me to be involved, and to be listening, and to be paying attention, when she goes over the notes and discusses. And with my history professor, he talks at the class for fifty minutes. Um, there aren't clicker questions. It's not interactive at all. And that, you know, I've no interest in that. He's obviously passionate about it, but I'm not feeling any of that because…I can't relate to it when he doesn't relate it to me, I guess.

This is an indication of what is lacking from the students' perspective when there isn't an interactive element to the course.

Marie (FI) compared the use of clickers in her chemistry course to a theater course in which they are not used:

> So in chemistry…there's a lot of, like, concepts that you have to grasp… but you don't have to, like, discuss with each other what you feel about…all the different concepts in chemistry…you have to be able to apply them and understand them whereas … in writing or theater…you can use more of your opinion…it's a lot more open to discussion I guess.

Dorothy (FI) had taken a course which was “more open to discussion” in which clickers had been used. The course was construction of femininities and masculinities, and the questions were more often about student opinions. She indicated that she didn’t find clickers all that useful in this application, even though the questions were often so sensitive that she might not want to tell everyone in class her answer. She stated, “I mean, I know my opinion, and it’s nice that the teacher would like to know it too, but it didn’t help as far as learning the class material.” There were no FD students who indicated having clickers in this sort of a class. If there had been, they may have had a different perspective.

Student Collaboration and factors which affect it.

Because student collaboration has been mentioned so widely in the literature as one of the benefits of clicker use, many of the focus group questions were designed to elicit responses on student impressions of collaboration (MacArthur & Jones, 2009). There was an initial question during the interviews, but much more time was devoted to the effects of student collaboration during the focus groups. A few unexpected factors emerged that appear to affect how students collaborate.

Students mentioned differences between the way the clicker questions were administered in chemistry versus how they were sometimes administered in other courses such as biology. In her interview, Anne (FD) described this difference:

> For chemistry that’s definitely promoted, we’re you know, able to talk with people …But for biology she’s also doing some sort of study…where um she presents the question and you’re given about a minute to answer it yourself without talking. And then the immediate minute following

> you're given that time to talk with your neighbors and maybe change your answer.

Benjamin (FM) had similar impressions of the difference in how the two classes were taught:

> In bio we're actively asked not to, and sometimes we are asked to talk with our neighbors. And um, she has done something which we haven't done in chemistry. Which is she'll ask a question. She'll have us all answer, silently. And then she'll have us talk to our neighbors and like debate what we thought the actually answer was….We haven't done that in chemistry. Chemistry … I can't think of an example where it wasn't talk to your neighbors see what you think.

Antoine (FM) had a similar experience in genetics, saying "The professor in genetics, sometimes she'll let us talk with our neighbor and sometimes she'll say do this independently."

The method used in these biology classes sounds very similar to the Peer Instruction method advocated by physics educator Eric Mazur (Mazur, 1997). According to student interviews, the number of correct choices when moving from individual to group responses increases, consistent with the results Mazur and others have reported for Peer Instruction. In the FI focus group, Mariah said, "The percent of the right answer always, almost always goes up by 10, 20 percent, maybe even more…based on between without discussion and with discussion." While the method used in these biology courses does illustrate the power of student collaboration, the students don't necessarily think they learn anything more from the method used in the biology classes than they do in the method used in their chemistry classes. When asked which one he preferred, Benjamin (FM) said:

> I think they're pretty similar in the long run. I think it's pretty interesting as like an exercise to see how people thought: solo versus group. Really though…it seems just a study in how the kids are thinking. Um, having done it a couple times it enforced for me the fact that I really do need to talk to other people because they might have a different understanding of

> it and we can come to a joint conclusion that might be a little more accurate than just one person…But, um, all in all I think it's really very similar. Because really it does come down to group work does seem to be more effective.

Despite this, many students did indicate that they often will decide an answer on their own before beginning to discuss with classmates. Marie (FI) says in her interview, "At first I like to try to figure out myself just to see if I understand the material, and after I answer or while I'm in the process of clicking I'll ask around and see what other people are thinking." Similarly, Edith (FI) adds, "yeah, I think about the question if I can try to figure it out on my own, and if I can't I ask ideas. I pretty much always verify my answer with another person." And Mariah (FM), "yeah, I usually try to tackle it by myself and then if I'm kind of sketchy I'll ask someone else or if I feel pretty confident I'll just ask and be like 'hey what do you think it is.'" In the FD focus group, Anne says:

> The girls that I usually sit with will sort of think of the answer and try to figure it out and then we'll kind of compare with each other. So, like, if we all have the same answer we're going to click the same answer but ones we're going to argue the answers that we got and whichever one makes more sense we'll sort of unilaterally decide that that's right. So we'll all choose the same answer, usually.

Although both FI and FD students indicate some amount of thinking about the question on their own first before discussing with others, these responses feel different. The more FI students appear more personal in this reflection, while the more FD student appears more communal in her approach to this. This difference will be elaborated upon more in Chapter V.

The students generally liked discussing with their classmates, and found it to be very effective. Benjamin (FM) said, "But the idea is see if talking to other people you can come to a more accurate conclusion. And usually we do. Um, which I thought was pretty interesting." In her interview, Lise (FD) said," It gives us a chance to ask our

neighbors what they think the answer is and discuss why it might be that, why it might not be that. So you can meet the people and learn their opinions and ideas at the same time."

Not all students' impressions of student collaboration were entirely positive, however. In her interview, Anne (FD) said:

> I like being able to discuss it, but usually the people I'm sitting with are the people that I'm studying with anyways. So our level of understanding is probably about the same just because we're studying together…So sometimes it seems more of, like, a waste of class to discuss…at least for me because I'm talking with the same people every time.

But then in the focus group she said, "I just find it really, really helpful to sort of bounce ideas off of other people and hear what they have to say. And, um, you know sort of just get a feel for how the class is picking up a concept and like whether or not I'm keeping pace with the class." So although there were some mixed feelings about student collaboration, even the student who initially had expressed some lack of satisfaction with it seemed to have developed an overall positive impression.

Some students indicated that interacting with other students was helpful in resolving a sense of being lost in a question. Benjamin (FM) said, "But a lot of the times I think it's better to talk with somebody…if you can't figure out when you have to work by yourself then it's going to be a bit of a problem, but if there's multiple people you might be able to come up with a solution." In the FI focus group, Marie said:

> If you're just by yourself working, you don't really know if you're doing it correctly… it's helpful to talk to other people and just see where they're at… and just see if you can find a common ground. And it helps to study with other people and just to hear feedback and just to talk about the material. And it's especially helpful with, like, the clicker question …to be able to figure out together how to do it, and having to do the problem and find the right answer.

Ruth (FM) said, “If you don’t know then you’re kind of like ‘oh well I’ll just guess’ and then it doesn’t really help you. But it seems like when you work with other people if you guys both don’t know but you can kind of…talk through it and work it out a lot more times you’ll understand.”

Some of the students elaborated a bit more on the thought processes associated with student collaboration that might make it so effective. Dorothy (FI) said, “You might not see something that someone else beside you did. Whereas I’m better with math… I can just do things in my head better. My best friend, she’s really good with concepts and so she can explain structures that sort of thing better…so it’s a lot easier to learn it I think.” In the FI focus group, Mariah said:

> I think there’s a lot of power when several people are working together… looking for just kind of like the silly mistakes and if I’m completely stuck on something usually someone will have [an idea] at least where to get started, and then maybe that’ll kind of have a snowball effect and then maybe I can figure it out and work from there. Um, and then just comparing answers and where did you get that and learning from each other.

Many of the students indicated clickers are very helpful in making them more actively engaged in their learning. Irene (FI) said, “I would say that another good thing that I like about clickers is that it forces you to pay attention all the time…So then you stay awake a little bit longer, you pay attention a little longer.” Marie (FI) said, “I think it’s a really interesting tool… to interact with the lecture and that way you’re not like falling asleep during the lecture.” Similarly, when asked what the class would be like without clickers, Ruth (FM) said, “I don’t think that there would be as much interaction with the students. I know a lot of people get on their computers and use facebook and fall asleep.”

In the FD focus group, Irene indicated the responsibility necessary to succeed at being a more active learner:

> I feel like college is one of those things where, like, if you want to do well you're going to put in the time to do it. So you're going to be active learning no matter what you're doing. And if you just kind of want to slide by, you know, if you're not going to try hard really on the clicker questions you're probably not going to be in chemistry because you're gonna, you know, [be] doing something else."

A few students indicated the value that active learning can have on the overall learning process. Antoine (FM) said:

> And just the fact that questions can be presented to the students to interact with and to talk to your neighbors about when you're trying to come up with an answer. So it's a good way to actually interact with the material as opposed to a lot of other large class lectures where the teacher just presents it, and it's harder to retain it as just a lecture without any sort of interaction.

Irene (FM) adds:

> But I also think it's nice to put kind of like a kinetic, you know what I mean, like you're talking about it so then since you're talking about it you're taking action in the question versus … just reading it...I've learned better that way if I can like see something written, write it out, and then talk about it and I remember it so much better than if I just read it.

These three factors (the difficulties with questions before beginning to interact, the powerful ability to solve problems when students do work together, and the retention of information when active learning methods are used) are indications of the effectiveness of social constructivism in this application of teaching with clickers.

Perhaps one of the most powerful applications of social constructivism arises in the occasions when students teach students, both for the teacher and the student. Benjamin (FM) described an occasion in which he taught another student how to find the right answer, "I was pretty sure. Like I understood the basics of it, but it forced me to think about it a little bit more in-depth so I could explain it to her so she would better

understand it so we could come to a better conclusion." In the FI focus group, Mariah explained her experiences with this:

> Not quite that I'm doing the work for them, but …showing them how to do this, then they do it, then show them how to do this, then they do it, now I need you to do it like this, and they do it this way. Like, I don't know, I feel like if I know it well enough to teach them how to do it then I really know the material. So that's always really good feedback for me.

Similarly, Lise explained in the FD focus group:

> I feel like I know the material better. I can explain to them why it is what it is, and then when we get the answer and she tells us how to do it, it's like satisfactory to know that I understood the concept or whatever. It makes you feel like I'll remember it because I can explain it to somebody else rather than just do it on my own [IRENE: and being able to teach someone else like cements that knowledge in your head, [nods] I think.]

FD participants indicated the type of student they interacted with was also important. Rosalind (FD) had this cautionary tale, "Sometimes like yesterday we have one in chem.[Laughs] and I was sitting by this other guy and this girl and she was like oh yeah it's definitely c) because if you do this and this and that was definitely not the right answer [laughs]. So sometimes it works to discuss it and sometimes it doesn't." When the FD focus group was asked how helpful they find the conversations, Irene responded, " Depends on who you sit by. [ANNE: yeah; ANNE, LISE, IRENE: Laugh]" and later added, "If I sit next to people, and they tend to get questions wrong, I stop listening to them." This dissatisfaction with poor collaborative experiences was apparently important enough to cause some of them to change where they sat in class.

This unexpected theme of how seating location affected collaboration emerged while I was asking a question about some things I had overhead during my classroom observations. This prompted a few students to question where I was sitting while observing the class, and they were not surprised to learn that I sat in the very back. When

I told Benjamin this, he said, "Yeah, that's what I was thinking. Because I think there's probably, I tend to sit up, my goal is like the first three rows." Irene, Anne, Ruth, Marie, and Benjamin indicated that they typically sat towards the front of the class. Edith, Mariah, and Antoine indicated they sometimes sat towards the back of the class, often because of available seats from arriving late or because of a need to leave class early. Other students did not indicate where in the class they sat. There appears to be a trend of students more likely to sit towards the back if they are FI and more likely to sit towards the front if they are FD. Evidence for this trend became even more pronounced during the focus group discussions.

During the FD focus group, students mentioned that through the course of the semester they had a tendency to move towards the front of the class because they found better people with whom to collaborate towards the front. Irene said:

> I think it also depends on where you sit in the lecture hall. [ANNE: yeah.] A lot of times if you sit closer you're going to have the kids that are more into doing well in chemistry. You know what I mean. So if you can sit near those kind of people and you can, like, listen to their thought process you can learn from that how to get your own. I've noticed that I do a lot better on my questions when I like sit closer... you're able to talk it out[which] I think is a big thing…which is what is difficult about an exam because [when]you, like, can hear it and hear yourself thinking through it you're able to pick up on your mistakes more.

Anne added, "I've noticed this slight like [ANNE, IRENE: laughter],[IRENE: gradually move into the front.] There was no indication of this type of seating change from the FI focus group.

In addition to the increased effectiveness of collaboration towards the front of the class, FD students indicated there were other distractions towards the back of the classroom. Lise said:

> I see facebook pages all over the place. People will be checking email or facebook, and …they'll also be taking notes on their notebook and they'll go back and forth between doing that and then like talking to people next to them. But I'm just like I have to take the notes on everything [ANNE: mhmmm] because I really understood the material best when it's taught in lecture, I can't just like read the book and be like oh yeah, I understand that.

Irene added, "I always just sit towards the front in all of my classes, just because…you don't have as many rows of distractions in the back, like you don't have as many facebook pages, you know what I mean (ANNE, IRENE: laughs), like games."

Student learning is affected not only by the group of students they are collaborating with, but often by the behavior of other groups of students as well, particularly for FD students. Three types of interactions appear to occur: overhearing other groups discussing the answer, other groups asking for the answer without having contributed, and other groups discussing things not related to the clicker question. These behaviors also appear to be related to the location in the classroom.

A few students mentioned the effect of overhearing other students discuss the clicker questions. Benjamin (FM) said "In terms of overhearing other people though, I think that does influence answers. In fact I know it does. 'Cause inevitably in a large class there's somebody that's going to be 'THE ANSWER IS B.' And then just go quiet again…it does seem to influence the clicking." In the FD focus group, Lise mentioned overhearing other conversations can sometimes be helpful in selecting the correct answer, "I always wait until I've gone through it and I don't have an actual, like, idea for it. I'll listen to the people around me, and I'll listen to how they reason it, and then I'll, like, go back through and think about it, and then sometimes I pick the right answer and sometimes I don't." She also says in one of her email responses, "I had trouble figuring the answers out and answered correctly because I listened to others around me reason

their answers." Mariah expressed a similar attitude in the FI focus group, "There's been tons of times where I just hear a group behind me talking about how they got to the answer, and I think 'yeah, that works for me' and I go with that because the people that are closer to me, we can't figure it out." This isn't always necessarily a positive, however, as Irene (FM) said in her interview, "So sometimes that can be really distracting because you hear someone else saying answers and then…you start questioning yourself."

Many students expressed frustration at other students who, not actively engaged in discussing the clicker question, were either asking them for the answer or just listening to their discussion without participating. Dorothy (FI) said, "The people behind us just click and they don't really discuss it at all, they talk amongst themselves. It's kind of frustrating, I guess, in a way." She elaborates on this further:

> Well they'll listen to us…we'll discuss it and we'll have the people beside us…we sit in the same spot every day …and towards the end [they'll ask] "oh you guys got E," and, you know, we kind of keep quiet but I'm pretty sure they're just clicking our question (laughs). So it's helpful for us though not for them. We're actually learning.

Anne (FD) expressed similar feelings in her focus group meeting:

> I honestly get, like, a little frustrated with people, like, if you're sitting in close proximity to people that you don't know and they're not talking at all but they, like, choose the same answer that you were just discussing. [IRENE: YEAH!] Like, that really frustrates me because it's not even just, like, that they're not doing anything…I mean I would [feel] better about it if they, like, talked it out with me, because I…want that input… Something about that just like really irks me.

Irene (FM) continued with this anecdote:

> I had a kid that would come and sit next to us and would do that: he'd sit there and do the calculus homework the whole entire class. A clicker question would come and he'd be like, "what's the answer?" and we'd all look at him and be like, "we don't know." [ANNE, IRENE: Laugh] and then he'd stop sitting next to us.

So perhaps student migration through the classroom over the course of a semester is motivated not only by some students desire to be around better collaborators, but also by other students' desire to be around those more willing to provide answers without collaboration.

Discussions unrelated to the clicker questions were particularly distracting to FD students. Lise said in the focus group:

> Sometimes I feel it's distracting because a lot of people take the opportunity of a clicker question to talk about something else…I try to reason it out in my head and I hear these people talking about something they did over the weekend and it's really distracting because I'm trying to block it out but they're so forceful in their story that it just keeps permeating in.

Anne, on the other hand, used these distracting conversations as a cue that she needed to finish up the clicker question, "So I start the question and if I haven't answered yet and I start hearing about people's weekends, I'm like 'oh hey, I've gotta hurry up,' because, you know, people are starting to finish and I've got to get answer up, so I use that as like a time factor. (laughs)"

A considerable amount of time in the focus groups was spent analyzing why students changed answers when discussing with others, whether correctly or incorrectly. They mentioned both their own comfort with the material as well as the confidence of the person they were talking with as factors influencing their decision. FD students tended to talk more about the person convincing them, whereas FI students tended to talk more about their own thought processes.

When students in the FD field group were asked what was important for changing their mind from whatever initial answer they had, they indicated good reasoning and confidence. Anne said:

> So if it's still like really fuzzy and you think you have it worked out when you talk to whoever you are next to, and they're like, "No, I'm 100% percent positive." You're like more like 95% positive [LISE, IRENE: Laugh] so we're going to go with your answer, and it's just such a bummer when that happens. Like oh, I knew it. [laughs] You feel like you should still get it.

Lise added, "well, maybe it's, like, the state of mind if it's a question that I'm not really sure on, and someone makes an argument and I know I'm not positive, I'm like 'well it sounds right' and I really just don't know. So it's, like, you go with it rather than…explaining it." Anne connected this idea to the confidence students feel when teaching others how to get the correct answer: "When you're explaining it you feel very confident about it. When you don't feel confident about it, and somebody's explaining it, they're confident about what they're explaining. So you, like, feed off that confidence and you're like 'well they're really confident about it, then it must be right.'"

Students in the FI focus group talked more about their own lack of knowledge when being convinced compared to the FD students' tendency to focus on the reasoning and confidence of the other students. Marie said, "If I got the right answer, it wasn't because I knew it, it was maybe that I…just randomly came up with that answer and was going to put it in and then after talking to other people they'd have different answers, but sometimes by chance you have the right answer to start out with." When asked what the most important factor in changing their mind was, Mariah said, "How they can explain how they got to the answer. Or how I can explain it. Whatever is, like, I guess more logical." Marie was in agreement, saying "I won't change my answer unless…I get a very good explanation like this is how I got to the answer or why it's, like, different than the one that I got."

Despite these differences in the focus group descriptions of how they were convinced of the right answer, all students lie on a continuum of field dependence, and some level of logic is probably important for convincing FD students and some level of confidence for convincing FI students. A quote from Edith, the student who had the highest FI score, illustrates this: "Depends how the other person is, and if they got it right and if they're convincing or not. Sometimes they might be very convincing with the wrong answer."

The importance of student collaboration is perhaps the most important theme that emerged from this portion of the study. There are many features that as a whole characterize the importance of student collaboration:

- how the question is administered to the class
- students' tendency (or lack thereof) to consider a question on their own before beginning to discuss with their neighbor
- increased effectiveness at problem solving when interacting with others
- greater retention of knowledge when active learning methods are used
- learning the material better when one has the opportunity to teach it
- types of students to interact with and how this varies with location in the classroom
- effect of other conversations on the learning process
- what sorts of things will convince students to change their minds about an answer.

The interrelatedness of these themes with the FDI nature of the students will be elaborated on in Chapter V.

Type of clicker questions and how students try to solve them.

An important part of characterizing the environment in which clickers are used is characterizing the sorts of questions that are asked. Other researchers are investigating the categorization of clicker questions used in chemistry courses (Towns, *et al.*, 2007, Mundell & Ferguson, 2008). Characterizing questions is not the primary goal of this research, however it is worth having a general idea of what sorts of questions are being used. Some of the themes emerging here relate to the coverage of the material relative to the question, understanding the question, categorizing the question, the thought processes students used to answer questions, "eyeballing" the answer, missing simple questions, and the importance of reading the textbook.

Students expressed a variety of opinions about the timing of clicker questions relative to the coverage of the material in the course. Some students claimed they had clicker questions over material not yet covered, although more students said this never happened. Some students preferred to have questions immediately after covering the material, while others preferred to have time to think about new content and have the questions on subsequent days. There didn't appear to be any correlation between students expressing that clicker questions covered new material and their tendency to be FD or FI.

Opinions over whether clicker questions were always over material already covered in class, or over material that had not been covered yet diverged. Rosalind (FD) indicated a few times in the interview that sometimes clicker questions address material not covered in class. She said, "I mean to make sure that you know you've gone over the

material pretty thoroughly before you throw up the clicker question. Because otherwise I just kind of feel, I mean me as a student I felt kind of lost. Because I don't know how to figure this one out yet because we haven't even really covered it." Mariah also mentioned this in her interview, saying, "but sometimes, you know, there's something we didn't learn or whatever. Throws you for a loop." However, when asked in the FI focus group if there were ever questions over material not covered in class she says, "I don't think so. I never noticed that." Marie indicated, "If it's before [covering it in class] it's usually, like, a review from the homework …or over the reading from the night before just …to review the material that we've been studying that week." More students indicated that the clicker questions were about material that they had already gone over. When asked if there were ever clicker questions over material not covered in class, Irene (FM) said in the interview, "uh, no, not that I've ever been in a class. I'm sure there are other classes that do that to test if you've read or not." This was the consensus of both the FD and FI focus groups, with Anne saying, "Only homework's like that.[Laughs]" Irene added, "I think she does a really good job of [it]…yesterday she put up a question that she hadn't talked about yet, so then she's like 'Oh, I need to go back and talk about it.' And then you get it really right because she just talked about it and she just told you what your answer was." Although both students in the FI focus group indicated they had never had questions over material not covered in class, their interview data suggest that they thought there had been such questions at one point in the course.

Only one student, Anne, mentions preferring to have time to let new material sink in and have review questions the following day, while most preferred to have questions immediately after covering the concept. Anne (FD) mentioned several times in her

interview that she did not like having clicker questions immediately after going over the material, saying, “If she’s just recently gone over the concept and I’m still familiarizing myself with it…so if I’m still like really shaky about it, I’ll usually let the person next to me start the discussion.” Irene (FM) found the clicker questions most effective, “when she talks about it and then right after there’s a concept question about it because then you can relate what you learned back to the question right away.” She contrasts this with, “Sometimes they put the…question on something that you learned last lecture. You know what I mean, so it’s a couple days after.” Similarly, Marie (FI) said in her interview, “I prefer getting questions about the material that we’re learning that day. That way because it’s fresh in my head.” Mariah’s (FM) comments in her interview reflect this viewpoint, as well as her earlier apprehension about questions over material that hadn’t yet been covered, “I don’t like it when we haven’t learned it yet. And I really like it when it’s review right after we learn something. And it’s like just cementing it for me.” Dorothy (FI) said, “A lot of … teachers have you click in for attendance and then they’ll have a question right after. And I don’t think that’s as effective as …teaching you something and then asking a question.”

Some students indicated the importance of understanding the clicker questions in order to get them right. Antoine (FM) mentioned this several times in his interview, saying, “So far it’s always been I misread something and they convinced me that it’s right. Or sometimes it’s been the other way, that they’ve misread something and I’ve convinced them that it’s right.” He also mentioned it in both of his email interviews, saying in the second one, “All 4 I have missed have been ones where I thought about the question the opposite of what the question asked.” Mariah mentioned similar things in

the FI focus group, “When I…misread it, when you talk to other people usually at least somebody will catch the mistake or have caught other peoples’ mistakes and be able to work through it and say this is why it’s this one or whatever.” Marie (FI) in her second interview indicates the importance of understanding the question, saying, “The questions involved thinking skills and in order to get the questions right, one had to really read the question carefully.” And further added, “The reason that I have been getting certain questions wrong, I have noticed is because I don't completely understand the question or that I don't read it properly, so I don't know what it is asking for. I quickly jump to the wrong answer rather than read through the other possibilities.”

There were even more differences in opinion among students about categorizing the questions than there were in whether or not questions were over material that had already been covered in class. Students were asked in the interview if clicker questions were more often recall, algorithmic, or conceptual. Usually, they talked out their descriptions of each question type as well, or were informed of what my understanding of each question type was. There were a wide variety of responses as to which question type was most prevalent in the course. Even more striking, in the email interviews, students were asked to categorize the clicker questions from three specific days, and students picked all three question types on any given day. Each class period had between two and four clicker questions, and students were not always clear about which of these questions they were categorizing. There was also likely a lack of clarity in distinguishing the difference between question types for the students. Categorizing clicker questions is an important area of research that is being explored by other researchers, so the data

pertaining to classifying clicker questions were not explored as fully as were other themes (Towns, *et al.*, 2007).

Students did offer some valuable insights into their thought processes while answering clicker questions. In her first email, Lise (FD) said, “I think it really helps when I know the plan or how to start a question/problem. I tend to feel lost if I don't know where to start.” Irene (FM) said in her second email, “That can be confusing sometimes on a conceptual level. Thinking through all of the questions and taking into consideration all of the options is important in getting them all right. Although this sometimes takes a long time, it is helpful because sometimes she will throw in a tricky word.” And Mariah (FM) indicated in her email that the reason for missing questions was because she “didn’t think through it.” Expanding on this idea of thinking, Irene FM) said in her first email, “Thinking through the questions with a critical mind was the most effective way to get the questions correct. For example, one of the questions asked what the limiting reactant was. In order to figure this out, we had to think about what the reaction would entail and the molar ratios of the reaction.”

Some of the student comments seemed to indicate that synthesizing concepts was an important part of answering correctly. Irene (FM) said, “Which I think is the hardest part about science classes, you know what I mean, like you can know the definition but you have to be able to apply the definition to something.” Marie (FI) wrote in her first email, “In order to get the answers right on the questions, one must know how to process the wording of the question. In other words, they must know what the question is asking. Then, using the material learned in class, be able to find the right answer from the choices given.” She expands on this in her third email, saying, “In order to answer them

correctly, one had to be paying attention to the lecture, not only from today, but from the past week. Then, you had to know how to read the question carefully in order to figure out what the question was asking. From there you could pick the right answer, based on the concepts."

Some students brought up the importance of being able to "eyeball" the correct answer. From the discussion with the students, I understand this to mean making a general estimate of the correct answer without using a calculator to perform the mathematics. In her interview, Lise (FD) said, "Sometimes we'll have calculations and sometimes those calculations don't necessarily need to be written out all the way. You can eyeball some of them." Although in her email response she says, "I'm not very good at eyeballing things without writing out my thought process." Her email response was used to elicit student responses in the focus group. None of the students responded to this particularly, though later in the FI focus group, Mariah did say, "If the calculations aren't too complicated, or if I understand them, I can pretty much always get them right. But if it's a newer concept then I struggle with them a lot more…It's usually a lot easier for me to work with the trends, and um eyeball that way instead of trying to write out the entire thing." Benjamin (FM) discussed how this idea changed the way he approached solving clicker questions:

> Calculating it wrong…it taught me to look into things more thoroughly before jumping to a calculator for instance. And it taught me to think differently in a way. Cause I wouldn't have otherwise. Every time I would have been like, "you know this is exponential I need to calculate this out." And [now] I'm like, "can I just eyeball it and see which one works," because apparently all our tests are multiple choice…but it forced me to think about that, which I wouldn't have otherwise done.

When asked what he learned from this experience, he said, "I was thinking too linearly. I needed to give myself more options. Like I was coming in being like,

‘number: calculator.’ And now I think more of like, ‘numbers: do I need a calculator? not so much, or yeah, maybe.’” Although he doesn’t use the word “eyeball,” Antoine illustrated this idea clearly in the following anecdote:

> But I think it’s better for the more conceptual questions to make sure you get the idea as opposed to really complex math ones. For example, our teacher presented us with one it was about just like the electron size and it was a division question and the three answers were extremely different in terms of order of magnitude. So it wasn’t about doing math and plugging numbers into the calculator it was if you understood things like size and relationships with each other. So it was far more conceptual than mechanics.

A trend emerged that sometimes students miss the questions that seem initially to be the most simple. In the email interview, Marie (FI) indicated, “The trend that I notice in the questions I have gotten wrong, is that they don't take much effort to get the right answer. They are simple questions that are asking of the following, which statement isn't true, or which formula wasn't calculated correctly.” This seemed like an important theme to investigate, so it was included in the list of responses for participants in the focus groups to discuss. Marie did not mention anything about her response in the focus group meeting, although there was discussion about it in the FD focus group. Irene said, “When the question came up I was like, ‘oh, I really know the answer to this one it has to be,’ you know, and then the chart goes up and you’re like, ‘how did I miss that?’ And she’ll go back and explain it and you’re like, ‘Oh, I just forgot to think about,’ you know, for that one.” There was much discussion about the possible reasons for missing these questions, but there was no consensus on what type of questions were typically missed, with Lise saying, “I think for some of those ones it seems like they’re usually conceptual questions for me.” But Anne responded, “I don’t

know, I'm a bit more conceptual and so I usually get those questions and…the ones that I usually have a bit more trouble with are the ones that you have to reason out." Some of this ambiguity likely has to do with the lack of focus placed on defining question types in the initial interviews.

Some students indicated that reading the textbook was helpful in obtaining the correct answer to clicker questions. In her email response, Ruth says the reason why she got the clicker questions right was because, "I've read ahead of where we are in lecture so I was able to grasp the concepts discussed more easily." Similarly, Mariah says in her email response that the homework set and reading were important for getting the correct answer, but in the FI focus group she says, "I don't get much out of the reading unless I already have a background in it, whether from before or from class…I can't get enough information out of it that's useful, most of the time."

Formative assessment and related themes.

Along with student collaboration, formative assessment is widely mentioned in the anecdotal literature as a positive aspect of using clickers (MacArthur & Jones, 2008). There was not as much of an effort to elicit student responses applicable to this theme as there was for student collaboration, because the literature indicates it is not as important as student collaboration (MacArthur & Jones, 2008). However, there were still several responses indicative of its importance, as well as the importance of similar themes. Related to formative assessment are themes such as instantaneous feedback and comparison to other students. These themes will be discussed in this section as well.

Students often mentioned ideas related to formative assessment as the reason why they enjoy the clickers. Irene (FM) said:

> I like the clickers because it forces you to know the material, and… it prepares you really well for the exams because they're the same kind of questions. And I really like it. Most instructors go through and tell you what the right answer is, why it's the right answer, and go through the reasoning of why the other ones are wrong. Which is a good test taking thing.

Ruth (FM) said, "And it's nice because in chemistry…it's for do you understand this. If you don't it's a heads up that you maybe go back and look at it." And further added, "[if] the whole class is, like, not as good then she knows OK, they're not getting this I need to go back over it."

Many students described formative assessment when they were asked why the professor is choosing to use clickers in the course. Rosalind (FD) said, "They think it just helps the learning process…I know my intro chem. teacher said like from her point of view it helps people learn. [To] see if they got the right answer. And then she'd go to the right answer and show you how to how to do it, or how to figure it out." In her interview, Lise (FD) said, "So if you have trouble on tests I think it helps you practice more." Edith (FI) said, "Just get an overall feel of how many people understand what's going on," and felt in particular that this was necessary in the large classroom, adding, "It's a class of over 400 people; there's really not a better way to judge quickly if the majority of the students are understanding the material."

The importance of formative assessment came up in the FD focus group as well. Irene responded to a comment from Anne saying, "At the same time I think that's kind of helpful, like I remember things better if I get them wrong. [ANNE: yeah.] So say that same question is on the exam, I'm going to remember better since I clicked it wrong,

because I had to go back and think about why I got it wrong, and why it's right." Later, in the focus group, Anne said, "I mean the clicker questions to me are like pop quizzes that are like constantly reminding you while you sit in class. And that's, you know, it's nice to have that reminder."

The value of getting instantaneous feedback for both the professor and the class seemed like a very important aspect of clicker use to some of the students as well. Mariah (FM) said in one of her emails, "They seem to give the teacher automatic feedback about how well the class is picking up on the lecture." In her interview, Anne (FD) said:

> I think it's she can see immediate results. You know where she goes over a new idea and she can see it immediately, or not only her but the rest of the class can see immediately the impact that it has on our idea of chemistry or, you know, how well she's getting an idea across. It's just like a very fast form of knowing of keeping track, I guess.

Similarly, when asked why the professor was using clickers, Ruth (FM) said:

> Just so the students can, like, and also her, [get] immediate feedback instead of, like, homework. You…get it right or wrong and I guess you can kind of learn from that but it's like a week later. But as she's going in the lecture notes, it can seem "Oh. Ok, they're really understanding this I can move on", [or] we didn't really understand this question so I might want to rephrase it.

The ability to compare to other students was also important to some of the participants. Marie (FI) said, "And then be able to see the way the other people answered. Because even…when you do questions like that in class you wanna know what other people are thinking." In the FD focus group, Anne said:

> [You] just get a feel for how the class is picking up a concept and, like, whether or not I'm keeping pace with the class…I like how she shows the histograms of, like, people who are getting it right versus people who are getting it wrong. It's good to sort of see, like, where I am in the class. It's like an "up to date keeps me on track."

Although these themes related to formative assessment were not explicitly addressed in the questions, students did find them to be important to their learning.

Other themes

A number of other themes emerged. Some of these often come up in the literature. Some of them were areas in which the professor teaching the course expressed interest. Some of them were intentionally explored, and some of them emerged in the course of the study. These themes are

- how class size affects clicker use
- technical difficulties with clickers
- the anonymous nature of clicker responses
- time management issues with the use of clickers
- how attendance relates to clickers
- concerns about the use of clickers as an invasion of privacy.

Each of these will be analyzed.

The size of the course was an important theme that emerged in the instructor interviews, so I also looked for student opinions on how the course size affected the usefulness of clickers. Some students indicated a general lack of comfort with the very large number of students in their chemistry course. Anne (FD) said "this is my first year in college and so you know it can be really overwhelming to enter a class of like 250 or 300 kids." Marie (FI) also indicated that a 400-person lecture hall was overwhelming, in her case because her graduating high school class had only 150 people in it. Edith (FI) indicated frustration with the over-enrollment because she was sitting on the recycling

bins, and was hoping some students would drop the course to make room in the chairs. Rosalind (FD) compared her experience in the 400-person chemistry class to a 200-person biology course she had taken several years ago. She said that even the difference between 200 and 400 people was noticeable, saying “it was just smaller and it felt more personal, I guess.” The 200-person course she was comparing it to had not used clickers.

Despite her frustrations with the course size, Anne indicated the clickers are very helpful in making these large classes at least feel more personal. She said, “It makes me feel like, you know, one of this many, you know it makes me feel like an individual instead of, you know, just this is the class and I’m talking at you.”

Many of the more FI students indicated they believe clickers are more effective in larger courses, and often attribute this to making formative assessment easier. When asked why clickers are more effective in larger courses, Antoine (FM) said, “the fact that all the students can answer…without wasting time of the teacher asking each individual person.” When asked why the teacher uses clickers in the course, Edith (FI) said, “it’s a class of over 400 people, there’s really not a better way to judge quickly if the majority of the students are understanding the material.” Marie (FI) said, “If there’s that many people in the class it’s hard to gauge, like, how many people are actually trying in the class, so to keep…all 400…tracking.”

The participants had a variety of opinions on the number of students necessary in a course to make the use of clickers most effective. Antoine (FM) said, “I think if there was like a class that was larger but smaller than the ones I was in, like 80 or so, it would probably be a good idea, but I can’t really say ‘cause I’ve basically got the really large and the really small and not a lot of in between.” Edith said, “I don’t think that clickers

are really needed in class sizes of 30. Those you can deal with hand raises and general discussion. But once you get more than 50 people it's just too much to deal with." When asked about the number fifty, she says, "Approximately. See my physics class is around 65 people and he used the clickers and it's small enough that we can ask questions, but for an overview it just isn't quite small enough to judge."

There has been mention in the literature that technical difficulties with clickers have been an impediment to incorporating them into the classroom (Hatch *et al*., 2005). Although the replacement of infrared clickers with radiofrequency clickers has mitigated much of this concern, there was some mention of technical difficulties from the student participants. In fact, most of the negative feedback from the students about clickers had to do with technical difficulties. In the FD focus group, students expressed some concern about their clickers not working sometimes, Anne said, "I also get really paranoid that my clicker's not working. [IRENE: I do that too. So I click it ten times. (laughs)] Exactly. Click it ten times. And so that doesn't help my stress level. 'Cause like once I get an answer and it's like not going so I click it over and over."

Most of this negative feedback had to do with dead batteries. Antoine (FM) said, "I've never heard people really talk about the actual clickers other than to say that they're running out of batteries." Edith (FI) said, "If there is any discussion that isn't about the question but is about the clicker, it's probably lack of batteries in the clicker or just small things like that, 'oh darn, I forgot my clicker,' 'it's running out of batteries,' or 'oh darn, I hit the wrong button.'" Many of the students mentioned dead batteries and forgetting clickers as related issues, as indicated in the FD focus group discussing when Anne said:

> I hear people say that sometimes they'll forget their clickers and that would kind of be a bummer.[IRENE: it's kind of frustrating when your

> batteries go out. (laughs)] oh yeah. [LISE: Yeah. I've heard that too. I've never heard anyone specifically saying "clicker questions are just a waste of time." I don't think I've ever heard anyone say anything like that. I've just heard like whenever the batteries go bad or I left it at home that day.]

Despite the frustration some students express from dead batteries and forgetting their clickers, they do realize that it is mainly their own responsibility to come to class prepared, as this quote from Irene's interview indicates, "I think mostly the reason why people don't like clickers is because people forget to bring them, their batteries run out, you know what I mean, things that could be preventable."

The anonymous nature of clickers is often mentioned in the literature as one of their potential benefits. However, it was very rarely mentioned by the participants as a characteristic that they valued. The only student who mentioned the anonymous nature of clickers as a positive was Lise (FD), who also mentioned she was very shy. She said about using clickers, "I like it. 'Cause you're able to participate more at the same time without everybody seeing if I'm wrong or not." Anne (FD) also mentioned anonymity, though her focus is on feeling connected to the class in spite of the anonymous nature of the response. She said, "And even though clickers are still, like, anonymous on some level, you know because you're not standing right there talking with the teacher about the answer…it makes me feel like an individual instead of you know just this is the class and I'm talking at you." Dorothy (FI) mentioned taking a class in which the clickers were used to ask more sensitive questions, but did not mention the anonymous nature as being important, and did not seem to think they were very useful in that course.

An area in which Dr. Thompson had expressed some interest was the amount of time spent on clicker questions. Because of this, there were a few questions about time management during clicker questions for the focus groups. Most of the students said they

typically had plenty of time to answer the clicker questions. Irene (FM) said, "It tells you the number of people who've clicked in so when the number gets around like how many people should be in the class is when she kind of stops it. I always think it's kind of funny though because like towards the end she'll say like OK and then like 50 people click in (laughs)." Although Marie (FI) seemed to indicate it might be more time than necessary, "Maybe if she made a specific like time limit, 'cause sometimes she'll extend the time if people aren't clicking in, but if she says this is how much time you have and if you don't make it in this specific amount then you just don't get the points or whatever."

Students did indicate that having a time limit on clicker questions affects the way that they think about them. Mariah (FM) says, "If it's a math question or something like that, I'll try to find a way to solve it without actually going through it. And solving the whole thing, like looking for patterns, something like that. But if I had the whole time, I might do that first and do the entire calculation, so that I know I have the solid numbers." Anne seems to indicate that she feels some of the questions were designed this way:

> I think a lot of her clicker questions are set up so that for, like, the most part you don't have to use your calculator, or at least a lot of the stuff that we've been doing right now…I think she understands that we feel encroached for time, that she moves pretty fast. Um, but then there are questions that, like, you could not get it unless you used your calculator.

Thinking about "the whole thing" is probably a better way to solve the problem than "doing the entire calculation." This mirrors some of the comments Benjamin had about how using the clickers changed his thought process.

However, some of the FD students indicated they sometimes felt rushed by the clicker questions. Anne says, "Depending on whether it's qualitative or quantitative. I mean usually if you gotta use some sort of equation it's like, 'ohmygosh' and it feels really rushed. But if its periodic trends or something you're like, 'oh, well this is more

than enough time, let's sort of move on.'" Lise said, "I think sometimes I'm worried about getting the right answer in time. And so I like rush to figure it out and then it's something that involves like calculations. My calculator doesn't always put in the right numbers so I get something completely off." In her email, Irene said, "Most of the questions I have been getting incorrect have just been calculation questions, mostly due to the fact that I am too worried about answering the question on time that I am not thoroughly thinking through the calculation."

A few students indicated they would click a button randomly before starting to work on the problem to ensure that they at least got the participation points, and then felt more at ease about taking their time to come to an answer. Irene said, "I usually click just one button so I can have that point and then I go back and change it after I've thought about it for awhile." And Mariah said, "What I usually do is as soon as she puts it up I click something so that I make sure that I get at least partial credit and then I go through and try to get the right answer and get the full points. But that way I don't have to worry about not getting anything and I can focus on the problem."

Many students indicated that having clickers in the course was a motivation for them to attend more regularly. The following story from Anne (FD) describes the feeling about this message:

> Honestly this morning I woke up late…I have chem at 8 in the morning. And…at first I was like "you know I'm not going to go, you know I've already woken up late and it's snowing and it's just going to be difficult to get there, and I'm going to be late anyways." And the reason I ended up going was because I knew I was going to miss points with the clicker questions. So…as much as I like the class, you know, just this morning I didn't want to go and ended up going late because of the clicker questions…clicker questions really are, you know, important that way in getting you to go.

In the FD focus group, Irene said, "I know I need to go to that class every single day just so I can have those points in case I do bad on the test." In the FI focus group, Marie said, "Not that I wouldn't show up every day, but it just gives me that much more motivation to come and try." Benjamin (FM), a post-baccalureate student, said, "I mean I like it that I'm getting the points for being there, but in retrospect my freshman year of college probably would have been good for me to have something forcing me to go to class."

Benjamin did, however, express some concerns about using clickers only as a means of taking attendance. He said:

> [initially I felt] like it's sort of, I don't want to say an invasion of privacy because that's just ridiculous, but that kind of thing. But I've gotten over that…I'm not sure why it felt so, I don't know, strongly about that at first. .. now that I've looked back on it, that's kind of ridiculous, really ridiculous. But I thought that's what it was.

When asked to elaborate on why he felt this way at first, he said:

> I don't think that would really serve a purpose than just showing that people showed up… More than anything I think it would be superfluous, like why? Maybe the beginning of the semester when you're trying to find out if you have slots in the class if you start showing up. It might be useful to do it then. But to have people to buy them specifically for that would be completely unnecessary I think.

It was the use of the clickers for more than simply taking attendance that convinced Benjamin that they were useful to his learning and not a money-wasting invasion of his privacy. This is consistent with the results that others have seen (King, 2008; Wood, 2004).

CHAPTER V

CONCLUSIONS

Each of the five research questions will be connected to the data that were collected. The first two research questions are specific to a set of data. That is, the statistical data will be addressed by the first research question, and the instructor interviews will be addressed by the second research question. The final three research questions draw much from the same data set, however. Additionally, a large portion of this set of data consists of responses from intermediate students (as opposed to field dependent or field independent), who were not addressed in any of these three research questions. Some initial conclusions will be drawn for questions three and four; however, the bulk of the discussion will focus on question five, which will also incorporate intermediate student behavior. Following this, a grounded theory will be developed from these data.

Q1 Are there demographic factors that correlate differently with student performance in classrooms that make use of clickers compared to classrooms that do not use clickers?

Three interesting ideas emerged from these data. It would be difficult to call them conclusions, as no experiment was performed in collecting these data, but the findings raise interesting questions. The psychology majors are largely pre-med students and the

results from both semesters indicated that they performed statistically better than undecided students before the use of clickers was implemented but didn't perform significantly better after the implementation (M. Asirvatham, personal communication, February 24th, 2010). In my experience, pre-med students have been highly competitive in their attempts to achieve high grades in their coursework. A possible explanation for psychology majors no longer performing better after the clicker implementation is that pre-med students have an increased tendency to cooperate with other students when clickers are implemented, possibly negating some of this competitive advantage.

Clickers might help students "get up to speed" when faced with new situations. The elimination of the decreased performance among transfer and international students when clickers are implemented is evidence of this. Some of these transfer students may be transferring after having completed the first semester of general chemistry at another school and are having a difficult time if the rigor of the coursework is not the same. The formative assessment aspects of classes taught with clickers might provide these students with enough information early on to show them that they need to focus more on the course to improve their performance.

Students who rely on the highly efficient use of poorly understood algorithms to solve chemistry problems might no longer be at a competitive advantage when the focus turns to molecular level concepts. Physics, Mathematics, and Engineering (PME) courses are traditionally filled with many algorithms, and chemistry can certainly be taught with a focus on algorithms as well. Although the physics department at this university has been a leader in shifting the focus away from algorithms towards conceptual understanding, students enrolled in general chemistry might not yet have had sufficient exposure to this

approach to change their perception of how to learn. There was actually a reversal in PME major performance from doing significantly better overall before the focus shifted to molecular concepts to doing significantly worse overall after the shift. A professor familiar with how the course is taught confirms that physics students often struggle with the conceptual nature of chemistry (M. Asirvatham, personal communication, February 24th, 2010). Studying the new focus on molecular level concepts is not the purpose of this work; however, this change does seem to be important for improving the learning of students in this chemistry course. Other researchers are responsible for this change and have reported on how it was brought about (Asirvatham, 2010).

The interaction terms lend support to the claim that students learn better both when the course is taught with clickers and when the focus is on the molecular level. Interaction terms for groups of students that existed before clickers were adopted were eliminated once the professors of the course began teaching with clickers:

- Transfer students and international students are no longer doing worse in Chem 1131than nontransfer students and white students, respectively.
- Psychology majors are no longer doing better in either Chem 1111 or Chem 1131 than students with undeclared majors.
- PME majors are no longer doing better in Chem 1111 than students with undeclared majors (although they end up doing worse once the focus on molecular concepts was adopted).

These changes are consistent with clickers facilitating a more egalitarian learning environment.

Q2 What are the similarities and differences in the philosophical approach of professors who have used clickers to teach large general chemistry courses?

The following factors appear to have been important for the success in teaching general chemistry with clickers observed at CU-Boulder:

- Having an institutional culture that promotes the use of clickers has made professors more likely to use them in their classes, and has made their implementation easier for the professors who do use them.
- Clickers seem to have had a more profound effect on increasing student interaction as the size of the class increases, though excessively large (~300 student) classes may not ever be effective, even with clickers.
- Clickers seem to have increased student attendance.
- There are multiple ways of using clickers to teach a chemistry course effectively: some are “natural implementations”, some more deliberate, but professors who have had success with clickers suggest that they shouldn’t be forced.

Some of the differences that emerged between the various professors’ implementations of clickers may have been due to the course level that was observed. Dr. Joule and Dr. Thompson were observed teaching the first semester of general chemistry, whereas Dr. Kelvin and Dr Gibbs were observed teaching higher levels. The tendency of professors to ask clicker questions that challenged students to think about concepts not explicitly covered in the course increased with the course level. This difference is consistent with commonly held educational beliefs about scaffolding

(Bransford, *et al.*, 2000). Student interview data (which will be discussed in more detail regarding questions 3 through 5) suggest that a mix of question difficulty might be appropriate, with some “easier” questions to help build student confidence mixed in with some “harder” questions that enforce the need for students to collaborate during the clicker questions.

The most obvious difference in professor opinions had to do with attendance. Although none of them were in favor of using clickers only for the purpose of taking attendance, most professors mentioned that clickers increased student attendance in general chemistry. However, Dr. Joule and Dr. Kelvin said this is a good thing while Dr. Thompson said it is a bad thing. Dr. Thompson’s concern was that unmotivated students would attend the class simply for the clicker points and engage in behavior disruptive to the learning of other students. Student interview data suggest that some students are very distracted by other students who are not in class to learn. However, these same students say that even though they are very motivated to attend class, the clicker points give them that much more motivation to come. So increasing student attendance appears to be both beneficial and a possible problem. Determining the weighting of clicker questions to get the right students to attend and the wrong ones to stay home appears to be a very subtle task which might be best determined by the professor teaching the course. Others have previously researched this issue somewhat (King, 2008).

Q3 What are the opinions of field-dependent student volunteers regarding how clickers are used in large enrollment general chemistry courses?

FD students had an overall positive impression of the course and the way that clickers were used in it. Anne said, "I just really like the way she teaches. You know, I like that her personality comes out in the way she teaches. And it's much more easy for me to be involved and to be listening and to be paying attention, when she goes over the notes and discusses." And Rosalind adds, "You know, so I think in that way they're definitely a good tool."

Student collaboration was important to FD students. Anne discusses this process:

> The girls that I usually sit with will sort of think of the answer and try to figure it out and then we'll kind of compare with each other. So, like, if we all have the same answer we're going to click the same answer but ones we're going to argue the answers that we got and whichever one makes more sense we'll sort of unilaterally decide that that's right. So we'll all choose the same answer, usually.

Although she does indicate an initial individual component to the answering of the question, the emphasis of this explanation seems to be on the communal discussion that emerges afterwards. FD students seemed to value the active learning aspects of clickers, as well as their tendency to learn more while helping others. FD students placed a value on the helpfulness of the students they interacted with, and would change who they interacted with if they found these interactions unhelpful, even moving to other parts of the classroom to do so. When the FD focus group was asked how helpful they find conversations with other students, Irene said, " Depends on who you sit by. [ANNE: yeah; ANNE, LISE, IRENE: Laugh]" and later added, "If I sit next to people, and they tend to get questions wrong, I stop listening to them." FD student participants tended to move towards the front of the class as the semester progressed so as to have more productive collaborations. Anne said, "I've noticed this slight like [ANNE, IRENE: laughter],[IRENE: gradually move into the front.]" FD student participants expressed

frustration with other students who wanted to be provided with the correct answers without actively participating in the discussion. FD student participants would change their answers when discussing with other students based on how convincing and confident they found the other student. Anne said:

> So if it's still like really fuzzy and you think you have it worked out when you talk to whoever you are next to, and they're like, "No, I'm 100% percent positive." You're like more like 95% positive [LISE, IRENE: Laugh] so we're going to go with your answer, and it's just such a bummer when that happens. Like oh, I knew it. [laughs] You feel like you should still get it.

FD students indicated they often needed to avoid distractions in the classroom. They mention that some students are often looking at facebook pages and playing games during class. Sitting towards the front of the class will help them avoid these distractions. They can also be distracted by other students' off-topic conversations while trying to answer clicker questions. Lise said:

> Sometimes I feel it's distracting because a lot of people take the opportunity of a clicker question to talk about something else…I try to reason it out in my head and I hear these people talking about something they did over the weekend and it's really distracting because I'm trying to block it out but they're so forceful in their story that it just keeps permeating in.

Some FD students prefer to have time to let new material "sink in" before having clicker questions over it. Anne mentions this on several occasions in her interview, "Because I wouldn't mind if they weren't actual points associated with the clickers, but … going over a concept and then immediately being tested over it is a little bit shaky for me."

Some FD and intermediate students mentioned the importance of "eyeballing" a question to decide on the correct answer. My understanding of what students meant by this is roughly estimating the possible answers to a question instead of doing calculations

and then blindly selecting whatever answer the calculator tells you, as described by Antoine, "So it wasn't about doing math and plugging numbers into the calculator, it was if you understood things like size and relationships with each other. So it was far more conceptual than mechanics." Lise was ambivalent about "eyeballing," indicating in one case that it was a method useful in solving the problems, and in another that she wasn't very good at it. Three of the intermediate students discussed the process of eyeballing the correct answer. Benjamin indicated that clicker questions helped to change the way he thought about approaching multiple choice questions with numerical answers, "Every time I would have been like, 'you know this is exponential I need to calculate this out.' And [now] I'm like, 'can I just eyeball it and see which one works.'"

FD students mentioned formative assessment as both one of the reasons they enjoyed the course as well as the reason why they thought the professor was using clickers in the course. Rosalind said, "I know my intro chem. teacher said like from her point of view it helps people learn. [To] see if they got the right answer. And then she'd go to the right answer and show you how to how to do it, or how to figure it out." They also value comparing how well they did relative to other students. Anne said in the focus group, " I like how she shows the histograms of, like, people who are getting it right versus people who are getting it wrong. It's good to sort of see, like, where I am in the class." FD students mentioned the value of instantaneous feedback, as well. Anne said in the focus group, "She goes over a new idea and she can see it immediately, or not only her but the rest of the class can see immediately the impact that it has on our idea of chemistry."

A number of other themes emerged for FD students. Some of them indicated that they felt a bit overwhelmed by the very large size of the course (>300 students). Many mentioned technical difficulties: forgetting clickers, hitting the wrong button on accident, and batteries going dead. They focused on the need for individual responsibility to avoid these issues. Some students mentioned that they did feel a bit rushed sometimes, although overall they felt that they had plenty of time. The time limit did affect the way some of these students thought about the clicker questions, often focusing more on the "whole picture" instead of focusing on performing the calculations correctly. Having clicker questions increased their likelihood of attending class.

Q4 What are the opinions of field-independent student volunteers regarding how clickers are used in large enrollment general chemistry courses?

FI students had an overall positive impression of the course, although they did have a tendency to be critical as well. Marie said, "I think it's a really interesting tool…to interact with the lecture and that way you're not like falling asleep during the lecture, um, yeah… I think the technology is really cool." However Dorothy mixes some criticism in with her praise, "The teacher is awesome. She kind of teaches like we're little kids, but I didn't like the class in high school, but I like it now."

Student collaboration was important to FI students. They mention that they often will try to answer a question on their own before they discuss with others, however. Marie said in her interview, "At first I like to try to figure out myself just to see if I understand the material, and after I answer or while I'm in the process of clicking I'll ask around and see what other people are thinking." Similarly, Edith adds, "yeah, I think about the question if I can try to figure it out on my own, and if I can't I ask ideas. I

pretty much always verify my answer with another person." Marie indicates the usefulness when she does collaborate in the following comment:

> If you're just by yourself working, you don't really know if you're doing it correctly… it's helpful to talk to other people and just see where they're at… and just see if you can find a common ground. And it helps to study with other people and just to hear feedback and just to talk about the material. And it's especially helpful with, like, the clicker question …to be able to figure out together how to do it, and having to do the problem and find the right answer.

FI students seemed to value the active learning aspects of clickers, as well as their tendency to learn more while helping others. They also expressed frustration with other students who wanted to be provided with the correct answers without actively participating in the discussion. Dorothy said, "The people behind us just click and they don't really discuss it at all, they talk amongst themselves. It's kind of frustrating, I guess, in a way." FI students indicated they were convinced to change their answers when they didn't have a good reason for their initial selection. Marie said, "If I got the right answer, it wasn't because I knew it, it was maybe that I…just randomly came up with that answer and was going to put it in and then after talking to other people they'd have different answers, but sometimes by chance you have the right answer to start out with."

The FI students in this study seem to prefer having clicker questions just after covering the material, as opposed to having review questions a few days later. Marie said in her interview, "I prefer getting questions about the material that we're learning that day… because it's fresh in my head."

Some FI and intermediate students mentioned the importance of correctly reading the clicker questions in order to answer correctly. Antoine and Marie mentioned this

several times. Marie said in her email interview, “The questions involved thinking skills and in order to get the questions right, one had to really read the question carefully.”

Some FI and intermediate students discussed their thought processes in solving clicker questions. Irene said in one of her emails, “Thinking through the questions with a critical mind was the most effective way to get the questions correct.” Marie analyzes a very thorough process in arriving at the correct answer, “In order to answer them correctly, one had to be paying attention to the lecture, not only from today, but from the past week. Then you had to know how to read the question carefully in order to figure out what the question was asking. From there you could pick the right answer, based on the concepts.”

FI students mentioned formative assessment both as one of the reasons they enjoyed the course as well as the reason why they thought the professor was using clickers in the course. Edith said the professor was using clickers, “Just to get an overall feel of how many people understand what’s going on.” They also valued being able to make comparisons to other students in the course. Marie said, “…and then be able to see the way the other people answered. Because even when you like when you do questions like that in class you wanna know what other people are thinking.”

A number of other themes emerged for FI students. Some of them indicated that they felt a bit overwhelmed by the very large size of the course, but also said that clickers helped to make it not quite so overwhelming. Many mentioned technical difficulties: forgetting clickers, hitting the wrong button on accident, and batteries going dead. Most students felt that they had plenty of time to answer the clicker questions. Having clicker questions increased their likelihood of attending class.

Q5 What themes are similar between these two populations, and what themes are different?

The response patterns of the participants provide some interesting data that will be discussed before looking at the actual responses themselves. Participants could respond in three ways: the initial interview, the email surveys, and the focus groups. There were no obvious differences in the patterns of response for the interview data as regards FDI grouping. The pattern that did emerge from the interviews was that more data were obtained in the later interviews than in the early interviews. This difference may have arisen from the increased exposure to the course for the participant, and also from the likelihood that I was becoming more adept at soliciting student responses in the latter interviews.

A pattern emerged from the email surveys, however. Only two of the three FD student participants were asked to participate in the email survey: Rosalind dropped the course after the first email response, and Lise responded to all three emails, but had the shortest responses of anyone who did respond. Of the three FI students, Edith never responded after the initial interview and Dorothy responded only to the first email survey, while Marie responded to all three, with by far the largest amount of data of any respondent. This response pattern is consistent with two aspects of FDI behavior. The FI tendency to be less influenced by authority might explain Edith's nonresponse, and Dorothy's limited response. Only Edith and Benjamin (FM) did not respond to the email surveys, and all other students still enrolled in the course participated in at least two. The relatively long response of Marie (FI) and relatively short response of Lise (FD) is

consistent with the tendency of FI individuals to feel more comfortable communicating at a distance (Zhang & Sternberg, 2007).

The difference between the behaviors of the FI and FD focus groups was the most striking of the three sets of data. In the FI focus group, the students responded directly to interview questions or not at all. They did not interact with one another; in fact, sometimes it appeared as if they did not respond because the other participant responded first. It was more like a set of parallel interviews than a focus group. The FD focus group was much more interactive: students used demonstrative hand gestures, responded both verbally and nonverbally to each other's responses, and sometimes even finished each other's sentences. Whereas the FI focus group appeared to suppress student responses, the FD focus group appeared to create more data via the interaction between the focus group participants. Although the number of students observed is very small, this behavior is consistent with the tendency of FD students to be more aware of social cues and to feel more comfortable being close to others when communicating There are many differences between individuals, and this finding is not meant to imply that additional focus groups of FD and FI students would behave in the same way, simply that in this particular case, it appeared that the use of a focus group was more effective in generating useful data among FD student participants than it was among FI student participants. Therefore the conclusions will have more to do with the behaviors of FD students than with the behaviors of FI students.

Differences in focus group behavior are also indirect evidence that FD students might be the ones who benefit most by the use of clickers. The focus group was chosen as a means of gathering data for this study because it closely approximates the way in

which students might interact while answering clicker questions. FI students seemed to compete to answer focus group questions, while FD students were constructing the answer out of the conversations they engaged in. According to social constructivist theory, this is the sort of interaction that is most likely to result in learning. The clicker questions might function more as a formative assessment opportunity for the FI students than an opportunity to enhance knowledge via student collaboration.

Figure 3 summarizes the various themes that emerged and the perspectives of students in each category relative to these themes. In some cases, students in two or more categories held certain opinions, but in other cases differences in student opinion are seen for different categories of students. The details of these results will be discussed in the following pages.

All student participants had an overall positive impression of the course as a whole and the way in which clickers were used in the course. FI students were more likely to include criticisms of aspects of the way the course was taught in their comments, however. Edith said, “In this particular class so far, in just two weeks of class, there have been several typos in the clickers, but that’s not so much the clickers fault as much writing the clicker program.” Dorothy had a positive overall experience, but qualified it somewhat, “The teacher is awesome. She kind of teaches like we’re little kids, but I didn’t like the class in high school, but I like it now.” This is in contrast to Anne’s comment, “I just really like the way she teaches. You know, I like that her personality comes out in the way she teaches. And it’s much more easy for me to be involved and to be listening and to be paying attention, when she goes over the notes and discusses.”

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<table>
<tr><th>Theme</th><th>FD</th><th>Intermediate</th><th>FI</th></tr>
<tr><td rowspan="2">Overall impressions</td><td colspan="3">Positive.</td></tr>
<tr><td>Sometimes stressful.</td><td></td><td>Minor criticisms.</td></tr>
<tr><td rowspan="2">Comparison to other courses</td><td colspan="3">Favorable, to either clicker or nonclicker courses.</td></tr>
<tr><td>Critical of other courses when there was less engagement.</td><td></td><td>Critical of other course’s pedagogy for various reasons.</td></tr>
<tr><td rowspan="3">Student collaboration</td><td colspan="3">Valued active learning aspects, help when lost, and tendency to learn more while helping others.</td></tr>
<tr><td colspan="2">Influenced by other students’ confidence and good reasoning. More selective about with whom they worked.</td><td></td></tr>
<tr><td></td><td colspan="2">Influenced by other students’ logic and when they knew they didn’t understand the material.</td></tr>
<tr><td rowspan="2">Interaction with other students</td><td colspan="3">Frustrated with “Scavengers.”</td></tr>
<tr><td colspan="2">Movement towards front to improve interactions.</td><td>Ignore “Scavengers.”</td></tr>
<tr><td>Distractions</td><td>Affects ability to do problems; leads to movement towards front.</td><td></td><td>One student: extenuating circumstances.</td></tr>
<tr><td rowspan="2">Clicker questions relative to coverage of material</td><td colspan="3">Most prefer having clicker question immediately after concept.</td></tr>
<tr><td>Some preference for more space between concept and question.</td><td colspan="2"></td></tr>
<tr><td>Understanding the question</td><td>No mention of importance.</td><td colspan="2">Important for correct answer.</td></tr>
<tr><td rowspan="2">Thought process</td><td colspan="2">Struggle with learning to “eyeball.”</td><td></td></tr>
<tr><td></td><td colspan="2">Discuss synthesizing information to arrive at answer.</td></tr>
<tr><td rowspan="2">Formative assessment</td><td colspan="3">Positive aspect of clickers; comparison to other students helpful.</td></tr>
<tr><td colspan="2">Value instantaneous feedback.</td><td></td></tr>
<tr><td rowspan="2">Course size</td><td colspan="3">Some feel overwhelmed by 300-400 person course.</td></tr>
<tr><td></td><td colspan="2">Believe more helpful in larger courses.</td></tr>
<tr><td rowspan="2">Technical difficulties</td><td colspan="3">Dead batteries, forgetting clicker, hitting wrong button.</td></tr>
<tr><td colspan="2">Importance of individual responsibility.</td><td></td></tr>
<tr><td rowspan="3">Time for questions</td><td colspan="3">Most indicate plenty of time.</td></tr>
<tr><td>Sometimes feel rushed.</td><td colspan="2"></td></tr>
<tr><td colspan="2">Think more about “whole picture.”</td><td></td></tr>
<tr><td>Attendance</td><td colspan="3">Motivator for all students.
Negative reaction if that is all they are used for.</td></tr>
</table>

Figure 3: Comparison of FD, intermediate (FM), and FI students’ perspectives on various themes which emerged in the student interviews, emails, and focus groups.

FD students were not critical of the way the course was taught the way that FI students were, seeming more willing to accept the course as it was. Anne did mention not liking that they had clicker questions immediately after covering the material, but this comment seems to be related more to her own confidence in the material than to a criticism of the instructional method. Rosalind mentions overhearing other students' criticisms, but was vague about what they were. Benjamin, an intermediate student, was initially critical of clickers but changed his mind when he saw how they were used. Benjamin and Ruth, both intermediate students, as well as Dorothy and Edith, FI students, compared the use of clickers in their chemistry course favorably to the way in which they had been used in other courses. Edith in particular was quite disrespectful in characterizing one of her other professors, calling him a "bumbling old goof," and saying "that class in particular was fairly horrible, nothing really with the clickers, that was the least of the issues." This comment is consistent with the finding that FI individuals are less influenced by authority figures (Zhang & Sternberg, 2007). The level of criticism of either the chemistry course or other courses expressed by the students in this study seemed to increase dramatically moving from FD to intermediate to FI students.

It appears that the three methods of data collection (interviews, email surveys, and focus groups) were useful not only for triangulation, but also for providing each type of student the method of communication in which they were most comfortable. There was no noticeable difference in the data available through interviews from the various student types. The email survey and focus group, however, did seem to elicit more data from FI and FD students, respectively.

FD, FI and intermediate students indicated the importance of student collaboration. All three categories of students indicated that they valued the active learning aspects of clickers and getting help when they were lost at the start of a question, as well as the opportunity to learn more while helping others. They also indicated frustration with other students who wanted to be provided with the correct answers without actively participating in the discussion.

Despite these similarities, there were some differences between FD and FI students when it came to student collaboration. FD students seemed to place a much higher value on the knowledge level of the person with whom they were collaborating than did FI students. When the FD focus group was asked how helpful they find conversations with other students, Irene said, " Depends on who you sit by. [ANNE: yeah; ANNE, LISE, IRENE: Laugh]" and later added, "If I sit next to people, and they tend to get questions wrong, I stop listening to them." There was no indication that this was a concern among any of the FI students. FD and intermediate students actually changed where they sat throughout the semester so as to have more productive student collaboration, inevitably moving towards the front of the class. In the focus group, Irene said:

> I think it also depends on where you sit in the lecture hall. [ANNE: yeah.] A lot of times if you sit closer you're going to have the kids that are more into doing well in chemistry. You know what I mean. So if you can sit near those kind of people and you can, like, listen to their thought process you can learn from that how to get your own. I've noticed that I do a lot better on my questions when I like sit closer... you're able to talk it out[which] I think is a big thing.

FD students also indicated being more easily influenced by the confidence of other students, while FI students more often mentioned logic as well as their own lack of

understanding of the material as the factors that would affect accepting another student's answer. Anne said in the focus group,

> When you're explaining it you feel very confident about it. When you don't feel confident about it, and somebody's explaining it, they're confident about what they're explaining. So you like feed off that confidence and you're like "well they're really confident about it then it must be right." And then really sure. So….you just sort of assume that "Oh. Ok, they know what they're talking about."

Whereas Marie said, "I won't change my answer unless…I get a very good explanation like this is how I got to the answer or why it's, like, different than the one that I got."

These results are consistent with the tendency of FD individuals to be more easily influenced by others and FI individuals' tendency to be better problem solvers (Zhang & Sternberg, 2007). The FI students indicated being more focused on their own shortcomings or the logic of the arguments than on the confidence of the student they were collaborating with, although they sometimes mentioned good reasoning as being important, such as when Edith said "Depends how the other person is, and if they got it right and if they're convincing or not. Sometimes they might be very convincing with the wrong answer." FD students were more easily influenced by the confidence of those they interacted with, and also more likely to be choosy about who they interacted with. There was no indication of being choosy about whom to interact with from any FI students. If the FD students are relying more on the confidence than the logic when they discuss answers, it becomes more important for them to choose wisely who they talk to. This need for better collaboration partners, along with their greater awareness of social situations may be what causes them to move towards the front of the class as the semester progresses.

Another factor which might be affecting the migration of FD students has to do with avoiding distractions. FD students mentioned being easily distracted by the off-topic behaviors of other students. This included playing games or checking facebook on laptops during class, and talking about non-chemistry related topics during clicker questions. FD students' tendency to migrate towards the front of the classroom is influenced by such distractions as well. Not only are they moving to have a better group of people to collaborate with, but also to avoid the distractions present towards the back of the classroom.

There were some indications that distractions were also an issue for FI students. After stating that the large course was a bit overwhelming, Marie said in her interview, "But it helps if I sit close to the front of the room…So that way I can really focus on the teacher and not the people around me." However, FI students did not volunteer information on changing their seating behavior throughout the course of the semester the way that FD students had. This behavior would be consistent with FD individuals being more aware of the larger context than FI individuals (Zhang & Sternberg, 2007).

The issue of laptops distracting other students may be a significant problem that the administrations of many universities will likely need to address. It is evident that some students use laptop computers for off-task behavior during class time, and that this behavior is distracting to other students in the course. However, some students have indicated that they sometimes use their laptops to take notes during class. The appropriateness of using laptops will vary with university culture. The administration at each university will need to decide the most appropriate uses for their particular university culture. The possibility that laptop computers in very large enrollment

classrooms can distract other students from learning is worth considering in this sort of decision.

Contrasting opinions on how the clicker questions related to the coverage of the material were expressed. Three possibilities emerged: clicker questions on material that had not been covered yet, clicker questions immediately after covering the material, and clicker questions as review a day or two after the material was covered. There were a variety of student opinions about these possibilities.

In the interviews, some students indicated that at times they had clicker questions over material that had not yet been covered in class. However, in the focus groups all students insisted this never occurred, even those who had talked about it happening in the initial interview. Both FD and FI students initially claimed there were questions over material not yet covered in class, and both FD and FI students later claimed this never occurred. The pattern was that early in the semester they mentioned having questions before the material was covered while later in the semester they did not. This pattern is likely due either to the professor changing the way clicker questions were selected throughout the semester, or to the students changing their study habits (for example, reading before class more often) throughout the semester, and is not correlated to FDI categorization.

A pattern regarding students' preferences for clicker questions relative to the coverage of the material emerged. Both FI and intermediate students indicated they would much prefer to have clicker questions immediately after covering the material, while only one FD student, Anne, indicated wanting more time between covering material and having clicker questions. This finding is consistent with FI students being

better problem solvers than FD students. Because there was only one student who indicated wanting more time, it shouldn't be generalized to all FD students. And having clicker questions only as review the day after they are covered may seem to the students to eliminate some of the formative assessment aspects of their use and provide less motivation for students to pay attention to the material as it is being covered.

A variety of themes related to the important characteristics necessary to get the correct answer to clicker questions emerged. These themes overlapped from FD or FI into intermediate students, but did not seem to be shared by all students: importance of understanding the question, and the thought process for solving the question.

An FI and an intermediate student mentioned the importance of correctly reading the clicker questions in order to answer correctly. Antoine and Marie mentioned this several times. This theme did not emerge for any of the FD students, however. It seems that reading correctly would be an important part of solving the problem for any student, and so the failure of FD students to mention this factor is somewhat puzzling. Because FI individuals are generally believed to be better problem solvers, this observation doesn't likely mean that the FD students are so good at solving these problems that they are unaware of the need to read the problem carefully. Perhaps it indicates that these FD students are less likely to engage in the metacognitive thinking necessary to arrive at this conclusion; that is, they are less able to step back and objectively look at what they have done to solve the problem.

FI students seemed more likely to analyze their thought processes when solving clicker questions, while FD students tended to focus more on "eyeballing" questions. More intermediate students than either FD or FI students responded consistently with

both of these themes: of the intermediate students, Benjamin, Irene, and Mariah had comments consistent with these themes, while only Lise and Marie had such responses among FD or FI students, respectively. Some FD and intermediate students mentioned the importance of "eyeballing" a question to decide on the correct answer; however, this practice was not mentioned by FI students. Some intermediate students used phrases like, "not thinking about it" or "Thinking through the questions with a critical mind" to explain the process that they used. Marie (FI) has perhaps the most cogent explanation, "In order to get the answers right on the questions, one must know how to process the wording of the question." Although Marie offered more thorough explanations of how she solved the questions than any of the other students, the other FI students provided very little feedback on their thought process in comparison to the intermediate students. This is further illustrated by the contrast between Irene saying, "Thinking through all of the questions and taking into consideration all of the options is important in getting them all right. Although this sometimes takes a long time, it is helpful because sometimes she will throw in a tricky word," and Edith saying, "Sometimes they word things to try to trick but it's no big deal." Likewise, the only FD student who provided feedback on the thought process was Lise, who said "I think it really helps when I know the plan or how to start a question/problem. I tend to feel lost if I don't know where to start," and also expresses ambivalence regarding the "eyeballing" process. More research would be necessary to establish any trend between student thought processes and their FDI tendency.

Using both the classroom observations and the student interview responses, a general picture of the way in which clickers are used in the course emerges, regardless of

how each individual clicker question is categorized. Clicker questions appear most often to be used to apply new concepts immediately after covering the material. This application is often presented in a manner very similar to examples already covered; there may be some need for the student to incorporate ideas presented earlier in the course with this new material, but there does not appear to be the need for synthesizing new knowledge in order to obtain the correct answer that is present in the PI method advocated by Mazur (Mazur, 1997). Although the clicker questions used in this course are less difficult than what Mazur suggests, there are a number of reasons why this discrepancy is likely appropriate: 1) although Mazur's method clearly works, he doesn't present evidence for his claim that clicker questions resulting in correct answers ~50% of the time are more effective than clicker questions resulting in correct answers ~80% of the time; 2) Newtonian physics is often much more intuitive than general chemistry, so there may be reason to believe that questions beyond the scope of material coverage might be discovered by students more readily in physics than would be in chemistry; although other material is covered in these courses, the evidence presented for the effectiveness of these methods has been improved scores on the Force Concept Inventory; 3) while physics educators have in the Force Concept Inventory a selection of conceptual questions covering the material in the first semester of introductory physics, chemistry educators do not have such an established and agreed upon standard to guide the development of such questions. There may be some value in eliciting more productive discussions by creating more challenging clicker questions; however, some FD students such as Anne are already stressed out about the difficulty level of the current questions. The work on categorizing clicker questions will definitely be helpful in

determining the most appropriate difficulty for clicker questions in large enrollment general chemistry courses. Although the method of administering clicker questions in this large enrollment chemistry course was not consistent with the method proposed by Mazur, the data from this study indicate that it was effective in promoting student collaboration.

There was some indication from both FD and FI students that on occasion they will miss “simple questions” the most often. Marie mentioned this in one of her emails, stating, “The trend that I notice in the questions I have gotten wrong, is that they don't take much effort to get the right answer. They are simple questions that are asking of the following, which statement isn't true, or which formula wasn't calculated correctly.” Although she did not comment when her response was brought up in the focus group. The FD focus group members, however, did respond to her statement, indicating that it seemed to happen quite often. There was no consensus among them on what type of questions these were, however.

FD, FI, and intermediate students all mentioned formative assessment as both one of the reasons they enjoyed the course as well as the reason why they thought the professor was using clickers in the course. The value of being able to compare one’s work to that of other students was mentioned by both FD and FI students. Both FD and intermediate students mentioned the value of instantaneous feedback, although this was not mentioned by any FI students. It is possible that FI students might value instantaneous feedback less than FD students, because FI students tend to do better at problem solving and are less likely to be influenced by authority figures (Zhang &

Sternberg, 2007). They may be confident enough in their own choices that they don't need someone telling them they got it correct as much as the FD students do.

Two students, one FD and one FI, indicated that they felt a bit overwhelmed by the very large size of the course. Both students who indicated this were freshmen, one from a graduating high school class less than half the size of the chemistry course. FI and intermediate students indicated that they believed clickers became more necessary as course size increased. FD students made no mention of this. This seems at first to be the opposite of what would be expected, as FD students are typically more aware of their surroundings (Atwater, 1994). It's unclear why FI students made mention of this effect but FD students did not.

Technical difficulties were mentioned by FD, FI, and intermediate students. These were forgetting clickers, hitting the wrong button by accident, and batteries going dead. Although all categories of students mentioned these technical issues, only FD students focused on the need for individual responsibility to avoid them.

All student types indicated they generally had plenty of time to answer the clicker questions, and that the professor provided good feedback on amount of time remaining to answer a question. FD students mentioned that they did feel a bit rushed sometimes. Some FD and intermediate students mentioned that the time limit on the questions affected the way they thought about them, sometimes looking at the "whole picture" instead of focusing on performing the calculations. This focus on the "whole picture" might be caused by the "changing their thinking" practice that some of them mentioned when discussing the thought processes they used in answering some of the questions. FI students did not mention either a need to focus on the "whole picture" or a change in their

thinking. It is unclear whether time pressure does not help them to have an understanding of the “whole picture” or if they simply are capable of finding the correct answer via calculations in the time available. An understanding of the “whole picture” is consistent with FD individuals (Atwater, 1994) and it is possible that this time pressure is forcing them to think about the problems in a manner more consistent with their favored method of learning as opposed to focusing too much on the mechanics of performing calculations. More research in this area would need to be done in order to obtain a clearer picture of what is going on.

Many students, some from each of the three categories, said that having clicker questions increased their likelihood of attending class. One intermediate student indicated that he initially did not like clickers because he thought that taking attendance was the only reason they were being used.

Grounded Theory

The theory that emerged in this research concerned the dynamic nature of student collaboration within a large enrollment course. Analogies will be made between these interactions and chemical phenomena. Large enrollment science courses are similar to chemical phenomena in that the professor/investigator lacks the ability to control each individual student/particle, and relies on the ways in which they interact to obtain whatever product results. Just as certain chemicals when mixed together may generate either the desired product or unwanted side reactions, when students are “mixed” they

may interact in ways that could be helpful, hurtful, or neutral to their ability to learn the material. Clearly instructors want to have helpful interactions as much as possible.

The learning environment for clicker questions in this large enrollment chemistry course consists of three primary interactions: those between the professor and each student, those between students who have mutually chosen to interact with each other in answering the question, and those between students not choosing to interact with each other in answering the question. The basic decision which affects the way these interactions play out is each student’s decision of how seriously to interact with the question, and who to interact with while doing so. Students were not asked specifically about how they chose with whom to interact, but there were sufficient data from observations, focus groups and interviews, to come up with a model that sufficiently describes student behavior. Once this model was developed, it was compared to the findings of another researcher who did question students on how they chose to participate with one another (Hoekstra, 2008).

There appear to be two types of student collaboration and four types of student behavior regarding interaction. Students might have either intracollaboration or intercollaboration. I will define my usage of each of these terms. In intracollaboration students discuss with each other the reasons for their answers. During intracollaboration, all students involved in the collaboration are offering ideas on how to get to the right answer, or refuting ideas offered by others. Intracollaboration is a conversation: a dialogue (or trialogue, etc.). In intercollaboration students either say or hear things that other students hear or had said, but without the response. This might be simply overhearing the correct answer, or asking for the correct answer without an attempt to

engage the other student in understanding how they arrived at it. In intercollaboration, the learning of one or more of the students involved is not changed by the collaboration (though other behaviors might be, such as the student's choice to sit near the person asking for the answers). An interaction between students might, in some cases, transition in either direction, from intercollaboration to intracollaboration, or vice versa. There was little evidence to indicate what might cause such a change other than Irene's comment , "If I sit next to people, and they tend to get questions wrong, I stop listening to them." In this case, the transition was from intracollaboration to no collaboration at all. Intercollaboration might lead to intracollaboration if overhearing another students' comment prompts another student to decide to engage in a conversation with them.

Four categories of student interactors were identified: Friend, Loner, Scavenger, and Resonator. The characteristics of these four categories are summarized in table 11, and are further developed in the paragraphs that follow. These are not categories of individuals, but of ways in which they might act in a given learning environment. The same individual might behave in a manner consistent with either of the four interactor types depending on the course material, the pedagogic methods used by the instructor, the nature of the classroom, and the behavior of the other students whom they are sitting next to in the classroom. As will be discussed, some interactor types are more beneficial to collaborative learning environments than others. Teaching methods that increase the likelihood of students behaving consistent with these interactor types will be discussed.

Table 11: Types of interactors found in large-enrollment clicker courses.

Type of interactor	FDI type	Behavior
Friend	Either	Outside factors led to intracollaboration.
Loner	Probably FI	Not trying to interact. Confident or shy.
Scavenger	Either	Unmotivated or shy. Seeking to benefit via intercollaboration.
Resonator	Probably FD	Trying to improve intracollaboration.

Friends have intracollaboration based on factors not related to the clicker question: they are roommates, friends outside of class, enrolled in other classes together, or have some other reason for collaborating with each other independent of what goes on in the chemistry classroom. These are very strong interactions which are not likely to be disrupted based on how they interact, (for example, if they get the question wrong or right), though the interactions could be disrupted because of factors outside of the course itself, such as dissolving a friendship. These interactions are likely very useful, as the interactors may have a better understanding of each other's perspectives, as well as strengths and weaknesses of subject matter understanding. This is indicated in Dorothy's quote "You might not see something that someone else beside you did. Whereas I'm better with math… I can just do things in my head better. My best friend, she's really good with concepts and so she can explain structures, that sort of thing, better…so it's a lot easier to learn it I think." However, there are some potential drawbacks to these sorts of interactions, as indicated by Anne's quote:

> I like being able to discuss it, but usually the people I'm sitting with are the people that I'm studying with anyways. So our, um, level of understanding is probably about the same just because we're studying

> together…sometimes it seems more of like a waste of class to discuss…at least for me because I'm talking with the same people every time.

Friends may have similar personalities, learning styles, and knowledge levels of the material. If this is the case, they don't gain as much understanding of the material from the conversation as they might if they had a conversation with a student who has a different perspective. The intracollaboration between Friends is very strong. They may be the source of intercollaboration in that other students around them might hear their conversations and make choices based on them. Friends aren't likely benefitting much from intercollaboration in that they are sufficiently engaged with each other that overhearing other conversations isn't likely to occur as often as it might for students who aren't as actively engaged already. Of the student participants, Edith, Anne and Dorothy indicate from their comments that they might regularly have this type of interaction.

Loners are students who do not place value on the opportunity to interact with other students. They may be very confident or very shy, and may be field independent, based on the tendency of field independent individuals to be less comfortable communicating at close distances and less influenced by authority figures (Zhang and Sternberg 2007). They would rather answer on their own than participate in a conversation with another student to arrive at an answer. If they are behaving as a Loner, they are not having any intracollaborative interactions. If they do have intercollaboration with other students, they are likely answering students who ask them what the answer is. They do not value interaction with other students sufficiently to engage with them meaningfully, but perhaps do not mind providing the answer "for free" if being pestered by Scavengers. They are confident enough in their own choices that overhearing conversations from other groups of students does not have much of an effect on their

decision-making process. Interactors who are prone to be Loners are less likely to participate in a study such as this than are other types of students. In fact, none of the participants appeared to behave as Loners; perhaps Marie would be the closest. There is no direct evidence for this sort of interactor, in that none of the participants mentioned behaving in such a way, and characterizing interactors certainly wasn't something that I was focused on during classroom observations. However, I have seen students behave in this way during classes I've taught in which I've promoted student collaboration. Loners can be considered a hypothetical type of interactor that may be found under certain teaching conditions. However, it was unclear if such conditions existed in this particular course.

Scavengers are interactors who try to benefit from intercollaboration without engaging in intracollaboration. There are two types of Scavengers: active and passive. Active Scavengers will ask other interactors to provide them with the correct answer without any interest in actually engaging in a discussion about how to arrive at it. Passive Scavengers will listen to conversations around them to gain information without actively trying to engage in the conversation. Active Scavengers have characteristics that indicate they are the least motivated students. They are not interested in understanding how to answer the question, simply in getting the correct answer. Active Scavengers are probably the least likely to participate in a research study, as they are unmotivated even to participate in class; however, interviews reveal how other students react to them. Dorothy said, "towards the end [they'll ask] 'oh you guys got E,' and, you know, we kind of keep quiet but I'm pretty sure they're just clicking our question (laughs). So it's helpful for us though not for them. We're actually learning." And Anne said in the

focus group, “I honestly get, like, a little frustrated with people, like, if you’re sitting in close proximity to people that you don’t know and they’re not talking at all but they, like, choose the same answer that you were just discussing. [IRENE: YEAH!] Like, that really frustrates me.” Passive Scavengers might be unmotivated or might simply be shy and unwilling to begin an interaction. Unmotivated Passive Scavengers are differentiated from Active Scavengers in that they are less aggressive or might be engaged enough to be actively listening instead of being off task through most of the class including the start of the clicker question. Shy Scavengers are differentiated from Loners in that they are less confident in their own answers and more likely to be influenced via intercollaboration. They may be motivated or unmotivated. Some of Lise’s quotes indicate that she might often behave like a Motivated Passive Scavenger. In the FD focus group she said:

> but I think I’ve done that a couple times, but I always wait until I’ve gone through it and I don’t have an actual like idea for it, I’ll listen to the people around me and I’ll listen to how they reason it and then I’ll like go back through and think about it and then sometimes I pick the right answer and sometimes I don’t. But I always I don’t just wait for them to say the answer without trying.

Resonators are looking to improve their intracollaborative environment. They are seeking other students to interact with in a way that will not just help them get the correct answer, but also improve their understanding of the material. They are likely to be motivated but may not be confident of their knowledge in the class, and are likely FD students. Resonators dislike conversations that are unproductive, particularly Active Scavengers seeking the correct answers. Anne said in the focus group, “I mean I would [feel] better about it if they, like, talked it out with me, because I…want that input… Something about that just like really irks me.” They dislike this so much that they will actually sit in different parts of the classroom to avoid them. Anne said in the focus

group, “I’ve noticed this slight like [ANNE, IRENE: laughter],[IRENE: gradually move into the front.]” They may, however, seek to gain knowledge from intercollaboration by listening to other conversations or watching as people click their answers. Irene said:

> I mean I’m guilty of making sure everyone around me is clicking the same question that I am. [makes clicker motion] You know I mean like you kind of look over. But at the same time I’ve thought about what I think the answer is, so I’ve, like, put in the effort … and sometimes there’s those questions which you just don’t know you know so you have to ask other people but at least you put the effort in to try to do it.

Not only will they move to other parts of the classroom to avoid Scavengers, they will also move to improve the chances of more productive intracollaboration. Irene said:

> A lot of times if you sit closer you’re going to have the kids that are more into doing well in chemistry. You know what I mean. So if you can sit near those kind of people and you can, like, listen to their thought process you can learn from that how to get your own. I’ve noticed that I do a lot better on my questions when I, like, sit closer.

Inevitably, they will make their way towards the front of the classroom. Some Resonators may have interest in intracollaboration not just as a means of increasing their learning, but as a way to meet other students socially. Benjamin said, “I can’t think of an example where it wasn’t talk to your neighbors see what you think. And I like that. Partially ‘cause I don’t live on campus and I just moved here so it’s nice to meet people.” Of the student participants, Irene, Benjamin, and Anne indicated that they might regularly have this type of interaction.

There are a number of ways that different types of interactors might interact with each other. Friends have very strong intracollaborative interactions which last over the course of several lecture periods. Depending on the number of interactors involved in such a collaboration and their personalities, they may or may not be open to either intercollaboration or intracollaboration with Scavengers or Resonators, respectively.

Dorothy indicates a lack of openness to supplying answers to Scavengers among her Friends, "The people behind us just click and they don't really discuss it at all, they talk amongst themselves…. towards the end [they'll ask] 'oh you guys got E,' and, you know, we kind of keep quiet but I'm pretty sure they're just clicking our question (laughs)." Resonators will tend to avoid Active Scavengers. They are seeking intracollaboration, and Active Scavengers are primarily interested in intercollaboration. Anne said:

> I honestly get, like, a little frustrated with people, like, if you're sitting in close proximity to people that you don't know and they're not talking at all but they, like, choose the same answer that you were just discussing. [IRENE: YEAH!] Like, that really frustrates me because it's not even just, like, that they're not doing anything…I mean I would [feel] better about it if they, like, talked it out with me, because I…want that input… Something about that just, like, really irks me.

Resonators might have positive interactions leading to intracollaboration with either Motivated Passive Scavengers or Loners, but likely have to initiate these interactions. Loners might be neutral to such collaboration and therefore more willing to share their thought process, and Motivated Passive Scavengers are likely to be interested in intracollaboration, simply unwilling to start it. Loners might also be neutral to Active Scavengers, willing to engage in intercollaboration with them. Loners and Friends are content with their learning environment as is, but might be persuaded by one of the other types into some sort of interaction, depending on a number of factors. Resonators and Scavengers are seeking specific types of interactions. To make an analogy to chemical bonding, we could say that Resonators are trying to form something similar to a bonding molecular orbital, and Scavengers are trying to form something similar to an anion. Resonators are trying to engage in a manner that improves the overall learning environment for everyone (analogous to lowering the energy levels of the orbitals), while

Scavengers are trying to engage in a manner that improves their score on the question without necessarily benefitting the other interactor, or even really benefitting themselves.

Treisman has found that Black students in an elite university setting begin their university studies with a strong sense of personal responsibility that often results in a low level of interaction with other students while studying (Treisman, 1985). If Black students in the chemistry courses under consideration for this study are behaving in the same way as the students in the Treisman study, they are likely behaving as Loners during the clicker questions. Because student collaboration is the primary benefit to learning in courses taught with clickers in this way, they are likely not benefiting as much from the use of clickers as students who are more open to intracollaboration. This hypothesis is consistent with the finding that Black and Hispanic students continue to underperform in the course, even after the change to teaching with clickers.

The tendency of Resonators to move towards the front of the classroom to improve their intracollaborative environment could have a profound effect on the classroom environment. It is known that there is a correlation between seating location in a typical classroom and student grades (Pedersen, 1977). However, the magnitude of this relationship might be greatly exaggerated in a large enrollment clicker classroom. In a typical classroom, the seating location might affect how easily a student is distracted, and might be indicative of student motivation. In a large enrollment clicker classroom, seating location may also affect the sorts of interactions that are occurring between students. There may be richer intracollaboration near the front of the classroom where the Resonators are concentrating, and weaker intracollaboration near the back of the classroom where the Active Scavengers are more concentrated. Motivated FD students

may also tend to move towards the front of the classroom in order to avoid distractions that exist in the back of the classroom (such as an unmotivated student checking their facebook or having conversations unrelated to the course).

A potentially enlightening conclusion can be drawn from the results of these interactions. If Friends and Loners are not likely to change their interaction without some interference from the other two types, then they can be thought of as being overall neutral to the benefit of interaction among students. Active Scavengers are certainly not benefitting the interaction among students. The only real effect that they have is to cause Resonators to move elsewhere. In fact, they could be thought of as being overall slightly negative to the interactive environment, as they are less likely than either Loners or Friends to engage in intracollaboration. Resonators always interact in ways that improve the learning environment, whether it be with other Resonators, Loners, Passive Scavengers, or Friends. Resonators can be thought of as driving the success of large enrollment clicker classrooms. If Resonators were not present in the class, the predominant type of intracollaboration might be between Friends who are likely meeting outside of class to study as it is.

Hoekstra (2008) conducted research in the exact same setting from 2003-2005. Although there have been some changes to the way the course has been taught between 2005 and 2009, her research setting is still very close to the research setting in this study and the results of her research are assumed to be generalizable to the subjects of this dissertation. Some of the questions that she asked pertained to what causes students to choose to talk to one another during clicker questions (or intracollaboration, as I've

referred to it in this dissertation), a question that wasn't answered in the data from the present study.

Hoekstra's work confirms that Loners are present in the class and offered some possible reasons for this behavior. Between 5 and 15% of the class indicated that they chose to work independently when answering clicker questions. Hoekstra listed three possible reasons for this choice: 1) they didn't want other students to realize they were unprepared, 2) they would rather wait for the professor to supply the correct answer than be influenced by incorrect students, and 3) they were free to behave on their own in the large course and the instructors were not enforcing collaboration. She also indicates that students are more likely to discuss with each other if the question is more difficult and that they become more accustomed to doing so as the course progresses. Male students are more likely to work on questions alone than are female students, and students are more likely to discuss their answer with a female student than a male student if their regular discussion partners are not available.

The focus of this section of the dissertation is the development of a theory to explain how various types of student interactions might affect the learning environment in large enrollment clicker courses. The question of what causes student choices of collaborators during clicker questions remained unanswered from the data collected for this dissertation. Hoekstra's findings help to answer some of these questions, such as why some students choose not to interact when answering clicker questions. These noninteracting students could be both Scavengers and Loners. The Scavengers are perhaps the unprepared students who don't want to embarrass themselves and instead just ask for or listen for the correct answer. The students concerned with unduly influencing

or being influenced by others do not correlate with any of the data from this dissertation study. In this study, lack of confidence was more often associated with an increased desire for intracollaboration. Again, however, this study was not focused on determining the cause of student interactions when the data were being collected. If male students are more likely to answer independently, this might explain some of the lack of data, as most of the participants in this dissertation study were females. This model may, of course, be incomplete, and should not be taken as a set of broad generalizations. The reasons for this will be discussed in more detail in the limitations portion of this discussion.

This model of student interaction might explain the success observed when clickers were incorporated into these very large classrooms. Student interactions during clicker questions appear to be both self-selected and dynamic in nature. Resonators will change the intracollaborative environment by moving throughout the classroom to find areas in which it is optimized. These changes, which they bring about by their movement, appear to improve the overall learning environment in the classroom. As such, this situation can be described as a self-assembled learning environment. The behavior of the Resonators improves the intracollaboration without the professor having to take the time to assign them to groups, which could prove to be unwieldy in classrooms of 300 or more students. This behavior is modeled in Figure 4. Continuing the theme of chemistry analogies, the professor is labeled as a nucleation site: a location around which both more understanding of the material and more intracollaboration are likely to occur.

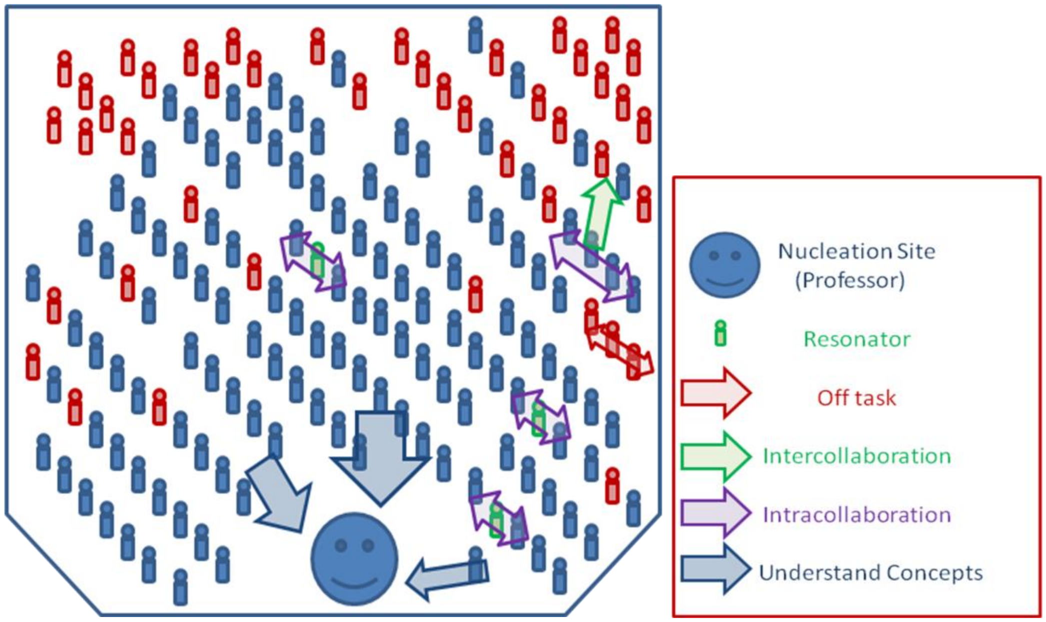

Figure 4: Model of student interactions in a clicker classroom. Resonators are creating more intracollaboration around themselves.

Recommendations for Future Work

The results of this study are tentative, but could be a good introduction to a potentially useful study of a much broader and perhaps generalizable nature. The student opinion data could be used to generate a survey that, combined with FDI groupings, could be used to test which of these results are in fact generalizable. Survey data could be collected during the class through use of the clickers themselves, and sufficient student participants might be obtained from recitation sections such that statistical analysis of the results would be appropriate. Questions which could be addressed by this study might include:

- How often and in what way do FD or FI students tend to interact with other students during clicker questions?

- What sorts of behaviors in other students affect FD or FI students tendency to interact with them?
- Does seating location or tendency to move throughout the semester correlate with either FD/FI groupings, or interactor type?

Further qualitative research could help answer additional questions about the nature of the theory that emerged:

- Are there more types of student interactors?
- What causes students to behave in ways consistent with each type of interactor?
- Why do students choose whether or not to discuss questions with each other?
- Most of the participation was from female students; would different themes emerge if more male students participate in focus groups?

Additional areas of potential research may focus on the thought processes students use while answering clicker questions and factors which affect them.

- How do students think differently based on the type of question (recall, algorithmic, conceptual)?
- What question difficulty is appropriate for engaging students metacognitively, and will this vary based on their FD/FI rating?
- How does the time available to answer the question affect the way they think about them?

- What approaches to learning are students using? Previously developed instruments are available to investigate this (Biggs, 1987; Entwistle and Ramsden, 1983)

Recommendations for Application

The success with clickers these professors have had suggests a few recommendations for professors who would like to begin using clickers at their own universities. Primarily, these professors found networking with other professors at the same university to develop the "clicker culture" to be important for the success observed in this study. For professors leading this development, Dr. Gibbs recommends reading successful reports of clicker use (see MacArthur, & Jones, 2008 for a review of many of these), and finding a way to observe their use in a fully developed situation such as this one in order to see what the possibilities are. In developing clicker questions, Dr. Kelvin recommends writing more conceptually oriented questions if possible. This seems to be a more difficult task than it initially appears to be; however, databases of conceptual questions exist (see MacArthur, & Jones, 2008 for a list of some of these). And finally, as Dr. Thompson said, avoid forcing the use of clickers. The most prevalent example of forced implementation I encountered in this study is using clickers primarily for the purpose of taking attendance. As Dr. Joule and Dr. Thompson stated, there appears to be widespread dissatisfaction among students who have seen clickers used only for attendance.

Based on the supposition that Resonators drive the success of clicker classrooms, it seems that improving teaching practice in large enrollment clicker classrooms would involve creating a learning environment in which there are more Resonators. This could be accomplished in two ways: by reducing the attrition of students likely to behave as Resonators or by creating a learning environment in which more students are likely to behave like Resonators.

Students likely to behave as Resonators seem to be most often motivated FD students, so methods of decreasing the attrition of these sorts of students might help maintain a higher concentration of Resonators throughout the course. This could be done if the course is graded in such a way that motivated students are more likely to succeed. Dr. Thompson said in her interview that she did not want the unmotivated students in the class distracting the motivated students. FD student interviews suggest that decreasing these distractions would be beneficial. Some FD students indicated stress when there were clicker questions in too close proximity to the coverage of the material or if they were too difficult. Lowering the difficulty of clicker questions might lower their stress level, and thereby their attrition level; however, it might also have a negative impact on the tendency of more confident students to interact. It appears that having a mix of question difficulties could provide a mix of different sorts of positive impacts. This is one possible way of increasing the success of motivated students, but instructors are encouraged to come up with strategies that fit this goal particular to their own courses.

Students who normally behave otherwise might be encouraged to behave like Resonators in a number of ways. Loners might behave like Resonators when they don’t feel confident in their answers. Friends might behave like Resonators if there were

reason to take on a greater amount of intracollaboration, or if the intracollaboration they did have was somehow disrupted. Motivated Passive Scavengers might behave more like Resonators if they felt more comfortable initiating an interaction. Active Scavengers might behave more like Resonators if they can be motivated. Of these possibilities, it seems the most easily attained would be to have harder clicker questions so as to encourage Loners to behave more like Resonators.

Resonators have a tendency to move towards the front of the classroom where the intracollaborative environment is much more conducive to learning. An analogy to chemistry can be made here, in which the professor at the front can be thought of as a "nucleation site" for good intracollaboration. Sometimes learning assistants (LA) are dispersed throughout the classroom for the purpose of helping the students with the clicker questions. Learning Assistants are undergraduate students who have already succeeded in the course and who have an interest in teaching. In addition to helping students answer clicker questions during the lecture, the LAs attend recitation sections, so the students know who these LAs are (Asirvatham, 2010b). Each LA can also be thought of as a "nucleation site." These "nucleation sites" are known to attract Resonators. Irene said:

> And sometimes they don't do so much now, but like the [LA's] will sit in the middle of the lecture hall…so you see them coming…you try to like save a seat for them. [laughs] So like if you ever have a really difficult question they're able to explain it. And I think that's really helpful. [ANNE: nods] You know 'cause there's always things that you miss and they obviously know what they're talking about.

LAs could change the way in which other interactors behave as well. The proximity of a "nucleation site" may increase the likelihood that a group of Friends will initiate intracollaboration outside of their tight interaction. This increase would be at least to

include the LA, and quite possibly any other interactors who are simultaneously interacting with the LA. Even Loners might be more likely to engage in intracollaboration, because they should understand that as confident as they feel, the LA likely has a greater mastery of the material than they do. The proximity to a "nucleation site" may increase the motivation of Active Scavengers as well as the likelihood of engagement of Passive Scavengers. If nothing else, it may increase the benefit of intercollaboration as Scavengers will be hearing more about how to arrive at the correct answer instead of hearing simply what the correct answer is. Figure 5 models the change in interaction that may occur in a clicker classroom when LAs are added to it.

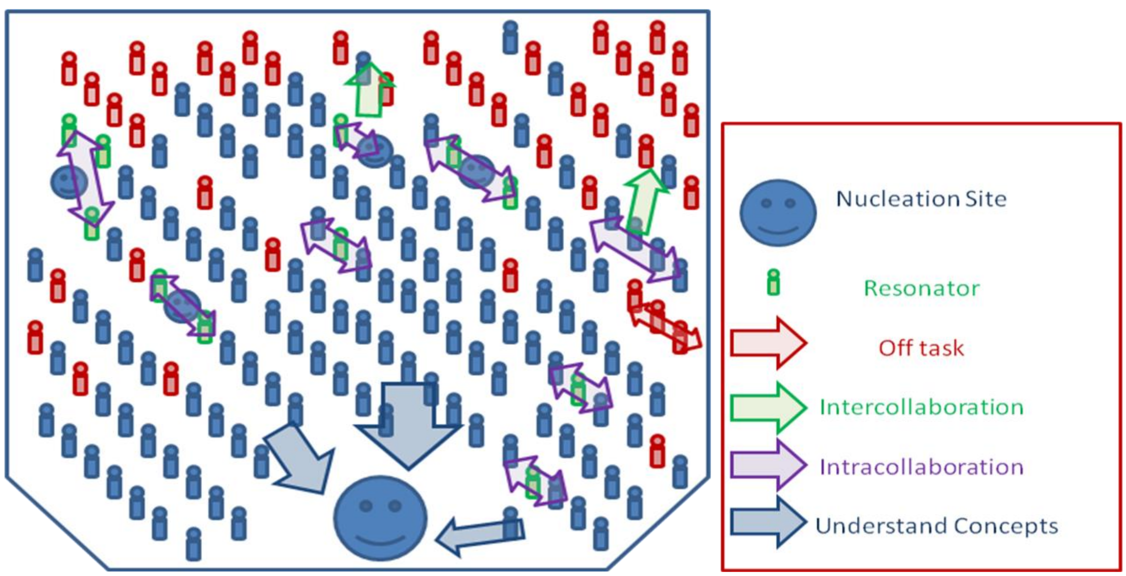

Figure 5: Model of student interactions in a clicker classroom with learning assistants. Learning assistants act as nucleation sites for student learning.

The practice of dispersing LA's throughout the classroom is designed to increase the amount of intracollaboration occurring; however, the question of what is the best placement for them remains. Because Resonators are known to seek nucleation sites, if

LA's are placed nearer the front of the class, there might be a tendency for motivated FD students to move towards an LA in the front where there are fewer distractions. On the other hand, if the LA's are placed towards the back of the classroom, they could more likely affect the behavior of Scavengers and Loners, causing them to behave more like Resonators while in their proximity. Of course, the LA's can be trained not to simply provide Scavengers with the correct answers.

Another way of increasing the amount of Resonator behavior is to create more challenging clicker questions. Creating questions that are challenging enough that Loners are not as confident in their selections might cause them to behave more like Resonators. This is consistent with the findings of Hoekstra (2008). There are possible drawbacks to this approach, however. Overly challenging questions might cause some students to behave more like Scavengers if they aren't sure where to get started. Some motivated FD students already feel stress with the level of questions currently used in the course, and increasing the question difficulty might lead to increased attrition of these students.

There is also some potential value in instructor comments that simply encourage the students to behave in a manner consistent with Resonators. "Don't just tell them the answer," might discourage the sort of intercollaboration by Active Scavengers that doesn't provide any learning. "Make sure to talk to someone even if you are sure of it," might encourage Loners to behave more like Resonators. "Talk to someone you don't know," might encourage Friends to behave more like Resonators. Professors who understand the more beneficial ways of interacting should be able to come up with their own set of prompts to encourage students to interact in desirable ways. Research in other methods of promoting student collaboration such as Process Oriented Guided Inquiry

Learning (POGIL) exists as well, and there may be some good advice on the types of instructor prompts for encouraging interactions at the POGIL website (www.pogil.org).

The recommendations for instructors resulting from this study are summarized in the following points:

- Develop a "clicker culture" at the institution to make implementation easier.
- Read the relevant literature and observe courses in which clickers have already been implemented in order to help in developing a "clicker culture."
- Try to develop more conceptually oriented questions, if possible.
- Avoid forcing clickers or using them primarily for the purpose of taking attendance.
- Select a grading method for clicker questions that will encourage motivated students to attend class.
- Find a way of teaching such that every student in the classroom is motivated.
- Having LA's dispersed throughout the classroom during clicker questions might improve the ways in which the students interact during clicker questions.
- Vary the difficulty of clicker questions throughout the course: easier questions may help FD students maintain their confidence, while harder questions might lead to more productive student interactions.

- Provide positive encouragement and feedback for FD students, who are more likely influenced by authority figures.
- Use verbal suggestions during clicker questions to encourage the best sort of interactions among students.

Limitations

Even if a controlled experiment was possible, the nature of this research does not lend itself to generalizability, as it involves student interactions. The difficulties of performing education research have been compared to the difficulties of performing research in quantum mechanics (Cooper, 2008). It would seem peer instruction, like other educational practices based on students interacting with one another, is particularly prone to making such an analogy. The analytical solution to the Schroedinger equation becomes unsolvable for the case of a many-electron atom due to the interactions between the electrons and their unpredictability. Students are likewise unpredictable, and their interactions with one another in peer instruction, though shown to be effective in learning, are equally problematic were it necessary to form a predictive theory for pedagogical effectiveness. Unlike electrons, however, students are in fact distinguishable, through not just demographics, but individuality. This distinguishability creates a greater complexity in the attempt to predict outcomes of educational research. While any two helium atoms (two electron systems) could be expected to behave identically, and experimentally this is shown to be the case, any two groups of even as few as two students would not be expected to show similar behaviors. Particularly,

students of a given demographic could not be expected to behave similarly when interacting within that demographic as they would when interacting with students of a different demographic. So the effect of instruction on a diverse population of students does not necessarily correlate to the effect on a minority population within a mostly homogeneous student sample. In short, the results obtained for this study may not be generalizable due to the dynamic and emergent nature of human interactions. However, a more detailed summary of the limitations in each area of the study will be outlined in the following paragraphs.

The main limitation of the quantitative section of this study is that it does not involve conducting an experiment. There is no control group and there are many uncontrolled variables. There are other possible changes besides the use of clickers and team teaching that may have occurred between the general chemistry course in 2002 and the one in 2003. Students were not randomly assigned to classes in which various teaching methods were used. As such, the results of this study can not be considered predictive of changes that would occur at other institutions if clickers were added to the course. This limitation is an inherent difficulty with educational research conducted in a realistic setting. Professors teaching the course are confident that the course has been improved by incorporating clickers into the class. It would be unethical to ask them to change back to the previous teaching methods, thereby hampering the learning of hundreds of students enrolled in the control section, simply to prove a point.

There are a number of possible limitations in the observation and professor interview portion of the study: limited transcriptions, incomplete member checking, and the evolving nature of my observations. There were significant technical difficulties with

obtaining recordings of professor interviews. I had a complete transcription for the interview with Dr. Thompson and Dr. Kelvin, half a transcription for Dr. Joule, and only field notes for the interview with Dr. Gibbs. Because of these technical difficulties, the quotations from the interviews rely more heavily on Dr. Thompson and Dr. Kelvin and less heavily on Dr. Gibbs and Dr. Joule.

My observation style evolved somewhat throughout the course of the study, and as Dr. Joule was no longer teaching after the first two observations, I was not able to collect the same sort of data that I collected in Dr. Thompson's class. When observing Dr. Thompson's class, I collected information on the amount of time spent on each question and at what point in the process the level of student interaction increased (based on the noise level in the classroom). I did not collect this information when I had been observing Dr. Joule's class. I believe that Dr. Thompson typically allowed a significantly greater period of time for the students to answer questions. In fact, part of my evolving style of observation was likely due to having a greater period of time within which to collect data in Dr. Thompson's class. The longer time for clicker questions in Dr. Thompsons's class may have been due to the subject matter in the later portion of the course moreso than it was due to any intrinsic difference between the teaching style of the two professors.

All the student participants in this study were enrolled in the first semester of general chemistry. Although not all student participants were freshmen, the overall behavior of the course may have been a freshman phenomenon. Student behavior might be substantially different in upper level courses where students have learned better study skills. Although the learning environment of freshman-level chemistry courses is in itself

an important area of study, it might not be indicative of student behavior in upper level courses.

There are additional limitations to the student interview portion of the study. The results are based largely on the opinions expressed by the 11 students who participated. The three FD students and three FI students may have expressed opinions that are not consistent with most FD or FI students, respectively. The focus groups contained intermediate students as well as the FD or FI students they were designed for. Some of these results may have been different if the focus groups were completely FD or FI. This is an exploratory study, and the results presented here are preliminary in nature. A larger study would be necessary to obtain generalizable results.

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APPENDIX A

STATISTICAL ANALYSIS: SAS CODE

```
dm output 'clear';
dm log 'clear';

DATA chem1111all;
infile "e:\boulder stuff\new\1111_all.csv" delimiter=",";
input GRADE Click_year M_Und M_MCDB M_bio M_chem M_psych
M_Physmatheng M_othersci M_other Eth_Asian Eth_Black Eth_Hisp Eth_NatAm
Eth_Unk Eth_White Eth_Int Gender Transfer FAMRES MATH VERB COMP HSGPA
miss amtmiss;
if FAMRES =4 THEN FAMRES=1;
if FAMRES =3 THEN FAMRES=1;
if FAMRES =2 THEN FAMRES=1;
if Click_year=2 then click_No =1;
if Click_year=2 then click_vis =0;
if Click_year=3 then click_No =0;
if Click_year=3 then click_vis =0;
if Click_year=4 then click_No =0;
if Click_year=4 then click_vis =0;
if Click_year=5 then click_No =0;
if Click_year=5 then click_vis =0;
if Click_year=6 then click_No =0;
if Click_year=6 then click_vis =1;


PROC CORR DATA=chem1111all;
  VAR GRADE click_No click_Vis M_Und M_MCDB M_bio M_chem M_psych
M_Physmatheng M_othersci M_other Eth_Asian Eth_Black Eth_Hisp Eth_NatAm
Eth_Unk Eth_White Eth_Int Gender Transfer FAMRES MATH VERB COMP HSGPA
amtmiss;

title "chem1111all";
PROC GLM DATA=chem1111all;
	MODEL GRADE= click_No click_Vis M_MCDB M_bio M_chem M_psych
M_Physmatheng M_othersci M_other Eth_Asian Eth_Black Eth_Hisp Eth_NatAm
Eth_Unk Eth_Int Gender Transfer FAMRES MATH VERB HSGPA
click_No*M_MCDB click_No*M_bio click_No*M_chem click_No*M_psych
click_No*M_Physmatheng click_No*M_othersci click_NO*Gender click_NO*Transfer
click_NO*FAMRES click_No*M_other click_No*Eth_Asian click_No*Eth_Black
click_No*Eth_Hisp click_No*Eth_NatAm click_No*Eth_Unk click_No*Eth_White
click_No*Eth_Int click_No*MATH click_NO*VERB click_NO*HSGPA
click_vis*M_MCDB click_vis*M_bio click_vis*M_chem click_vis*M_psych
click_vis*M_Physmatheng click_vis*M_othersci click_vis*Eth_Asian
click_vis*Eth_Black click_vis*Eth_Hisp click_vis*Eth_NatAm click_vis*Eth_Unk
click_vis*Eth_White click_vis*Eth_Int click_vis*M_other click_vis*Gender
click_vis*Transfer click_vis*FAMRES click_vis*MATH click_vis*VERB;
	OUTPUT OUT=stat1 PREDICTED=yhat1 RESIDUAL=err1;
```

```
PROC PLOT DATA=stat1;
        PLOT err1*yhat1;
PROC UNIVARIATE DATA=stat1 NORMAL PLOT;
        VAR err1;

RUN;
QUIT;
```

APPENDIX B

INSTRUCTOR INTERVIEWS: IRB, INFORMED CONSENT DOCUMENT AND INTERVIEW PROTOCOL

Application for exempt IRB approval

I Research Question

What are the experiences of instructors who use clickers in large enrollment chemistry courses? What do instructors of large enrollment chemistry courses believe to be the advantages and disadvantages of using clickers? Do the instructors I interview have perceptions of clickers consistent with characteristics common among field independent thinkers? Although there have been many papers written by instructors about their experience using clickers in various college courses, they are all autobiographical as opposed to interviews conducted by someone else. I published a review article on clickers this summer, in which 76 papers were reviewed, 19 of which were about practical uses, and 37 of which were research articles. The most widely noted benefits in the practical use papers were formative assessment (N=12) and student collaboration (N=11). Although this does provide some insight as to the benefits of clicker use, a more in-depth analysis might be had by observing and interviewing instructors about their use of clickers.

II Procedure

Instructors of general chemistry at CU Boulder will be contacted and asked about their interest in participating in the project. Four instructors are anticipated to participate. Instructors who are interested will be informed that their participation will consist of two interviews lasting a total of 45 minutes to an hour, as well as observation of their class.

Instructors will be provided some minor compensation such as a T-shirt, coffee mug, or gift card as a token of appreciation for their willingness to participate.

Once the instructors have agreed to participate, they will be sent an e-mail with a series of questions on the way that they use clickers in their chemistry courses. Their course will be observed one or more times, and then I will conduct a face to face interview with each instructor. After transcribing and coding the data, I will send a copy of my conclusions to the instructors so that they can determine if I have accurately represented what they have said.

III Disposition of Data

Classroom observations and interview transcriptions will be identified using pseudonyms. Recording devices will be stored in a locked room on a separate campus from the instructors being interviewed, and recordings will be deleted once transcriptions occur. Any printouts of transcribed documents will be stored in a locked filing cabinet on a separate campus from where the interview was conducted. E-mail conversations, of course, can never be considered confidential, but will be conducted only through a highly secure UNC faculty email account.

IV Justification for Exemption

The questions in these interviews are not of a personal nature and all participants are over the age of 18. Also, the researcher is in no position to coerce participation.

V Documentation

Copies of informed consent letter, scripts for email interview and in person interview are attached.

VI References

MacArthur, J. and Jones, L. (2008), A review of literature reports on clickers applicable to college chemistry classrooms, *Chem. Educ. Res. Pract.*, 2008, **9**, 187–195

UNIVERSITY of NORTHERN COLORADO

Informed Consent for Participation in Research
University of Northern Colorado

Project Title: Use of Clickers by College Level Chemistry Instructors

Researcher: James MacArthur, PhD candidate in chemical education
Phone Number: (303) 406-8909

Dear [Professor],
I am interested in doing some research on your class this semester. I have been working with Margaret Asirvatham and Loretta Jones (my advisor at UNC) on researching the use of clickers in general chemistry courses. I've presented some of our findings at the Spring 2008 ACS meeting, the 2008 BCCE, and published in the July 2008 copy of *Chemical Education Research and Practice*. I believe that clickers can be a positive tool for the teaching of large enrollment science courses, and I'm hoping to find out a bit more about why. My plan is to observe some of your classes, and interview you about the teaching of your classes, and how you use clickers in your instruction.

My research will consist of three parts: observations of your classroom, a 5-10 minute email interview, and a 20-40 minute audio-recorded interview after I observe your class. The questions I will be asking have to do with your views about advantages and disadvantages of clickers, how you use them in class, and how often you use them in class. I will use pseudonyms in my field notes and transcriptions in order to protect your confidentiality.
Please feel free to phone me if you have any questions or concerns about this research and please retain one copy of this letter for your records.

Thank you for assisting me with my research.

Sincerely,

Jim MacArthur

Participation is voluntary. You may decide not to participate in this study and if you begin participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research. A copy of this form will be given to you to retain for future reference. If you have any concerns about your selection or treatment as a research participant, please contact the Sponsored Programs and Academic Research Center, Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-1907

_________________________________ ____________________

Instructor’s Signature Date

_________________________________ ____________________

Researcher’s Signature Date

Copies of interview scripts

Copy of script to be used in e-mail interview:

- How long have you been teaching with clickers?
- What courses have you taught with clickers?
- What is the student enrollment in these courses?
- What percentage of class time do you use the clickers?
- What do you think are the advantages and disadvantages of teaching with clickers?
- If you could pick one advantage that clickers give you in teaching, what would it be?
- Why is this advantage so important?

Copies of face-to-face interview scripts:

- Did the class today (or on the given date if an interview can't be performed on the day of the lecture) go about how you planned it to?
- Why did you select [pick an example clicker question] as something to have the students answer with their clickers?
- When you asked this question, you had the students [describe the method that was used, ie.- individuals responding or groups of students discussing before responding]. Why did you select this method as the way to answer the question?
- Do you ever use any other instructional methods with the clickers, and if so what are they?
- Which methods do you think you use the most frequently?
- What are you thinking about or focusing on while the students are making the choices with their clickers?
- What do you get out of using clickers when you teach?
- What do you think the students get out of using clickers?
- Is there anything else about your experience using clickers that you would like me to know about?

APPENDIX C

STUDENT INTERVIEWS: IRB, INFORMED CONSENT DOCUMENT, INDIVIDUAL AND FOCUS GROUP INTERVIEW PROTOCOLS, SAMPLE INTERVIEWS

Application for exempt IRB approval

I Research Question

How do student opinions regarding the use of clickers in large enrollment general chemistry courses relate to their field dependence/field independence? There has been a recent increase in the use of clickers in large enrollment science courses because they are believed to increase student engagement with the material. Field-dependent learners are less likely to choose careers in science and are also more easily influenced by opinions of others when making decisions. Teaching methods used in a science course that increase students' engagement with each other and with the material might improve student perceptions of the field of science among field dependent students.

II Procedure

Student volunteers will be selected from the general chemistry course at CU Boulder. Students will be informed of the opportunity to participate via both in class and online announcements. Student volunteers will be contacted via email to arrange a meeting time for interviews. During the interviews, students will be asked questions about their experiences with using clickers in the general chemistry course. At the end of the interview, students will be asked to take the Embedded Figures Test. They will also be provided with a list of questions to answer about their experiences answering clicker questions in class. They will be asked to provide email responses to these questions one day a week for three or

four weeks. Students will be evaluated on their embedded figure test results, and grouped into either field dependent or field independent categories. Students from each category will be invited to participate in a focus group. Ideally there will be one focus group for field dependent students and one for field independent students, however if the number of volunteers is limited there may be only one focus group. All interviews will be audio-recorded, and the focus group might be video-recorded as well as audio-recorded. Students will be compensated for their time with a $15 gift card at the completion of both the interview and the focus group.

III Disposition of Data

All student identification will be stored in a locked room separate from the remainder of the data. Identification codes will be used to contact students if necessary.

IV Justification for Exemption

The questions on this survey would not be considered sensitive by most people, and the researcher is not in a position to coerce participation. The student participants will be compensated for their time with a gift card at the end of each meeting.

V Documentation

A letter of permission from the professor teaching the course at the University of Colorado will be obtained.

UNIVERSITY of NORTHERN COLORADO

Informed Consent for Participation in Research
University of Northern Colorado
Project Title: Use of Clickers in Large Lecture Chemistry Courses

Researcher: James MacArthur, PhD candidate in chemical education
Email address: james.macarthur@unco.edu

Dear student,
I am interested in doing some research on your class this semester. Clickers are becoming extremely popular in large lecture science courses, and the University of Colorado has been one of the leading universities in the country at promoting their use. I am conducting a study on student opinions regarding how clickers are used in chemistry classes.
My research will consist of a sixty minute audio recorded interview on your perception of clickers. A portion of this interview will be a 25 minute cognitive test. If you do choose to participate, your time will be compensated with a $15 gift card at the completion of the interview. You will also be asked to provide feedback on the course through email on a weekly basis over a period of about a month, and might be asked to participate in a future followup study. I will use pseudonyms in my field notes and transcriptions in order to protect your confidentiality. Possible benefits of participating in the study are an increased awareness of how you learn chemistry, which may improve your performance on exams. There are no perceived risks for participation.
I will contact you in the near future if you are chosen to participate in this study. Please feel free to email me if you have any questions or concerns about this research, or you may contact my advisor, Dr. Loretta Jones, at Loretta.Jones@unco.edu. Please retain one copy of this letter for your records.
Thank you for assisting me with my research.

Sincerely,

Jim MacArthur

Participation is voluntary. You may decide not to participate in this study and if you begin participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research. A copy of this form will be given to you to retain for future reference. If you have any concerns about your selection or treatment as a research participant, please contact the Sponsored Programs and Academic Research Center, Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-1907

______________________________ ____________________
Student's Signature Date

Student email address	Student phone number
Researcher’s Signature	Date

Informed Consent for Participation in Research
University of Northern Colorado
Project Title: Use of Clickers in Large Lecture Chemistry Courses

Researcher: James MacArthur, PhD candidate in chemical education
Email address: james.macarthur@unco.edu

Dear student,

I am interested in doing some research on your class this semester. Clickers are becoming extremely popular in large lecture science courses, and the University of Colorado has been one of the leading universities in the country at promoting their use. I am conducting a study on student opinions regarding how clickers are used in chemistry classes.

My research will consist of a sixty minute audio recorded interview on your perception of clickers. A portion of this interview will be a 25 minute cognitive test. If you do choose to participate, your time will be compensated with a $15 gift card at the completion of the interview. You will also be asked to provide feedback on the course through email on a weekly basis over a period of about a month, and might be asked to participate in a future followup study. I will use pseudonyms in my field notes and transcriptions in order to protect your confidentiality. Possible benefits of participating in the study are an increased awareness of how you learn chemistry, which may improve your performance on exams. There are no perceived risks for participation.

I will contact you in the near future if you are chosen to participate in this study. Please feel free to email me if you have any questions or concerns about this research, or you may contact my advisor, Dr. Loretta Jones, at Loretta.Jones@unco.edu. Please retain one copy of this letter for your records.

Thank you for assisting me with my research.

Sincerely,

Jim MacArthur

Participation is voluntary. You may decide not to participate in this study and if you begin participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research. A copy of this form will be given to you to retain for future reference. If you have any concerns about your selection or treatment as

a research participant, please contact the Sponsored Programs and Academic Research Center, Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-1907

Student's Signature	Date
Student email address	Student phone number
Researcher's Signature	Date

Interview Protocols.

First meeting:

What is your major, and how does taking a chemistry course relate to it?

What year are you in school?

How do you feel about your chemistry course?

How do you feel about using clickers in the course?

When do you find the clicker questions to be most effective?

Have you overheard other students making comments during clicker questions?

Based on what they've said, what sorts of impressions do you think other students have about using clickers in the class?

Why do you think the professor is using clickers in the course?

Sometimes chemistry teachers try to put their clicker questions into categories. One set of categories might be recall, algorithmic, and conceptual. How often do you think the clicker questions you've seen in the course fit into each of these categories?

Have you used clickers in any of your other courses here?

Can you compare the way the clickers were used in your chemistry course to how they were used in these other courses?

Is there anything else you'd like to say about how clickers are used in your chemistry class?

OK, then I would like to ask you to do 2 more things. I will be sending you an email shortly asking you to answer the following questions about how the class went with clickers on a specific day. These emails will be sent out a few times over the remainder of the semester, and you may be asked to participate in a further portion of the study later this semester.

The other thing I am going to ask you to do in the remainder of our time is take a cognitive test. These tests are a lot more difficult than they seem at first, but they will help to determine some aspects of the way you learn subjects like chemistry. Do you have any questions about this?

[Administer the Embedded Figure Test, 25 minutes]

Email portion:
Ask students to respond to the following list of questions via e-mail for a few select days.

- Are you satisfied with your performance on the clicker questions today?
- What do you think was important for getting the right answer on the questions you got right?
- If you missed any of the questions, why do you think you got them wrong?
- Do you notice any trends in the sorts of questions that you have been getting wrong or right?
- Categorize each of the clicker questions from today as one of the following: algorithmic, conceptual, or recall.
- Is there anything you think is important to share with others about the way clickers were used in the course?

Focus Group Interview Protocols:
Do you feel you regularly have enough time to answer the questions posed to you with the clickers?

> How do you think the professor could make the timing of clicker questions better?
>
> How do you think being "on the clock" affects the way you think when answering them?

(hand out copies of some of the clicker questions):

These are some of the clicker questions that were asked throughout the course of the semester. Do you remember answering any of these questions and what that was like?

What parts of these questions did you find particularly difficult?

Did you ever get the right answer to one of these using a method completely different from the one that the professor used? If so, discuss this. Did you find the method the professor described to be useful in further understanding the material?

This is a list of some responses that students made regarding the sorts of questions they got wrong. Do any of these responses resonate with how you feel about some of the clicker questions? Discuss this.

"I seem to be able to answer more of the algorithmic questions, where calculations and a process are needed. Sometimes the conceptual or recall questions aren't as easy to answer because you don't have to solve an actual problem."

“The trend that I notice in the questions I have gotten wrong, is that they don't take much effort to get the right answer. They are simple questions that are asking of the following, which statement isn't true, or which formula wasn't calculated correctly.”

“I'm not very good at eyeballing things without writing out my thought process.”

I want to discuss a bit more what happens when you talk with other students about clicker questions. How helpful do you find these conversations?

Raise your hand if you ever had the correct answer and changed to the wrong answer because of the discussion with your classmate. So those of you who raised your hands, discuss what this was like.

Raise your hand if you ever convinced someone of the correct answer when discussing with your classmates. So those of you who raised your hands, discuss what this was like.

Raise your hand if you ever had the wrong idea and so did the person you talked to, and in the conversation you both ended up getting the right answer. So those of you who raised your hands, discuss what this was like.

When you are convinced to change your answer in a discussion, what is usually the most important factor in changing your mind?

Some of you talked about clicker questions in your other classes being graded differently. What do you think is the best method for grading clicker questions? Doesn’t have to be what they use in your other classes, it could be any method you could think of.

Do you think some students would spend less time thinking about them if getting the correct answer didn’t affect their grade in the class?

(How do you think the type of question would affect this?)

Do you think some students would share their ideas about if a question is right or wrong with each other more often if getting the correct answer didn’t affect their grade in the class?

Do you ever have clicker questions over material not covered in class? If so, what kinds of questions are these?

What sorts of complaints about clickers have you heard students making?

When I was observing classes, I sometimes overheard students saying they couldn’t even see the question. Why do you think they said that?

Transcript of interview with “Rosalind” (FD student)

I: So, um, how do you feel about your chemistry course?

S: Pretty good, I think I need to you know, review some things from intro.

I: Yeah, yeah

S: Because this one I know gen chem. has a lot of pretty [inaudible] stuff

I: Yeah. What about the clickers, how do you feel about the clickers?

S: Um, pretty good, I mean you know, I guess I wish they were like my other ones like I have a physics course and that’s just participation, and it’s it doesn’t matter whether you get it right or wrong.

I: Yeah, I have, I was going to ask about other classes later. So is it, so in the physics you get points for participating and the chemistry you…

S: you get two points for if you get the right answer and one point if you use the clicker.

I: And you would rather not get points for the right answer?

S: No, well I would but (laughs) but you know some of them are things that you know we haven’t gone over. So.

I: In the chemistry class?

S: Yeah.

I: You don’t like having questions on stuff you haven’t gone over?

S: Right. (laughs)

I: Is it that way in physics also?

S: No, he usually goes over most of the stuff.

I: So you’ve gone over it before...

S: Right.

I: …and then you, you…

S: …and then [inaudible]

I: …is participation

S: Right.

I: Are there any other differences in like the questions, not just the scoring but the questions?

S: You mean between the two versus?

I: Yeah.

S: Not really, I mean both of them involve your ability to calculate what you need.

I: Um, are there more in one versus the other or?

S: Um so far there’ve been more in physics.

I: Yeah.

S: And in chem., like I think yesterday we had one, two, and usually in phys…well I guess in physics we’ve probably just had two the other day too. So kind of varies in some ways.

I: Kind of hard to tell the first week…

S: Right, yeah (laughs)

I: …what it’s like.

S: ‘Cause they do a lot of lecture.

I: Yeah, um, well just you haven’t done it that long.

S: Right.

I: So after a month or so you’ll have a better feel for it perhaps.

S: I know in the intro chem. last year we had a ton of clicker questions.
I: Oh really, Ok. And you said they're both, they're similar in that they're both a lot of calculation.
S: Yeah.
I: Um, when do you find the clicker questions to be most effective?
S: Um, to be most effective? Um, I'd say like after like I said after she's gone over stuff in lecture and then it just kind of helps it sink in a little more.
I: So when you've already covered the material?
S: Yeah.
I: Um, have you overheard others making comments during clicker questions?
S: I mean as far, I mean, um, we'll talk to each other about you know…
I: Yeah, you'll talk, but do you ever hear another group nearby saying things during the clicker question?
S: You mean just about the clickers or about anything?
I: Usually about something to do with the clicker question?
S: Oh, with the clicker question. Um, I mean I have heard, overhead other people discuss it.
I: What kinds of things are they saying, like if anything pops out at you as being like an odd thing for someone to say, or…
S: No, not really, haven't heard any of that stuff.
I: Or anything that might indicate what they think about the clickers.
S: Well I heard a couple of times and this was in intro chem. people just didn't like them (laughs) they'd get frustrated with them sometimes.
I: Did, could you tell what they were frustrated with?
S: Just, I think maybe it was just they didn't like the clickers period as far as they didn't like using them, and you know.
I: But there wasn't anything to tell exactly what about them…
S: No. No.
I: I just have heard some random things people say sitting in class.
S: (laughs) No No I haven't heard anything at all.
I: Yeah, we might revisit that a bit later. Not today, but. Um, why do you think the professor is using, why do you think she wants to use clickers in the class?
S: Um, well I mean from both my chem. teachers they both said that it you know they think it just helps the learning process.
I: OK.
S: You know, review it, and see if you I mean I know my intro chem. teacher said like from her point of view it helps people learn so if they got the right answer and then she'd go to the right answer and show you how to how to do it or how to figure it out.
I: OK um, this one's kind of you might need to think about this a little bit. Sometimes chemistry teachers try to put their clicker questions into categories. One set of categories that a lot of people might use would be recall would be one category, algorithmic would be another, and conceptual. So do you know the difference between those?
S: Well the algorithms were the calculations right?
I: Yeah, yeah.
S: And then what was the other one?
I: Recall

S: Recall
I: And conceptual.
S: So just memory and then conceptual ok. Yeah.
I: Um, how do you think that the clicker questions you've seen in the course so far would fit into each of those categories?
S: We had a couple in algorithms so far. And then a couple have been conceptual. And not really any recall stuff. Not yet.
I: OK. OK. Um, we already talked about the physics course you have them in both. And you're a senior right?
S: Yeah.
I: So you've been around, been in a lot of classes. Have you had other classes that use clickers?
S: Um, biology.
I: Um, have you had a maybe large classes that haven't used clickers.
S: Um, let's see. Trying to think. 'Cause I actually just came back here last year. Been gone for a long period of time. (laughs)
I: Oh.
S: So I'm trying to think, did we use any in, we didn't use any in math, I haven't ever used any in math courses, so that I've had. Basically I've just had my science and math courses and then just a couple of English courses.
I: OK.
S: SO yeah, it's just been the science, two science courses, and then the physics one, too.
I: um, now you said you were away for awhile.
S: Mhmmm.
I: When you were in school before was it…
S: No powerpoint, no clickers (laughs)
I: Were there large classes?
S: Yep. Yeah.
I: Um, could you compare those large classes to how the large classes feel now.
S: Oh they, they were. I mean I remember my biology course a long time ago that I took and it was much smaller than the biology courses that I…
I: Oh it was smaller, OK. I mean did you have any 300, 400 person classes before.
S: Um, No. It's only one or two hundred.
I: Oh, OK. That's still pretty big. Um, how, how would you. So one of those maybe 200 person classes, could you maybe compare how that felt to maybe how the chemistry or physics class.
S: Um, I, I mean I, yeah. I think we were able to take more time you know on questions and going over stuff than than they do in, you know it seems like in the bigger classes they well and…
I: You took, you were able to have more time per question in the 200 person class?
S: And it was just smaller and it felt more personal, I guess.
I: Yeah, even 200 people felt more personal.
S: Yeah. (laughs) well I think that, I think in my chem. class we've got 450, close to 500 probably. And then I know biology last year was that way too. Cause they were both in chem. 140, which is the big auditorium.
I: So even the difference between 200 and 400?

S: Right.
I: You can see that?
S: Yeah.
I: So when you say more time per question, is that a question from a student or a sample question that the professor is going over.
S: Just from a student learning they were able to take more time going over just you know individual pieces of the lecture. So…
I: Um, and you said the math classes you took didn't use clickers.
S: No, because one was only 20 people in the trig class,
I: Oh, ok.
S: Algebra class and probably had like 30 in that.
I: So you're not having those big...
S: Right, and now I have a precalc class. But it's still around only has 100.
I: So you don't have any like 3 or 400 person.
S: No. No. No I don't have any of the large math classes.
I: Or any other subject?
S: No, not right now.
I: OK.
S: I mean I probably will eventually.
I: So you talked a little bit about comparing the chemistry and physics, how they used. What about the biology, that used the clickers?
S: As far as how they used the clickers?
I: Yeah.
S: It was the same as clickers. You got 2 points for being right and 1 point for being wrong. And then my intro was the same way. My intro chem.
I: OK. What about maybe the frequency of the questions or um the type of questions?
S: There were, there's, I mean as far as like you said it's kind of early now in chemistry. As far as biology went there were a lot of clicker questions. Because they used a lot of those questions for test. They just reworded or just changed them around a little bit. And um and basically I know in my chem. course now or my physics course they both said that their going to be using clicker questions, or forms of them in the exams. So.
I: OK
S: Which I mean as far as that goes I feel that that kind of helps with studying because part of its you know, you know that part of its going to be from the clicker question.
I: What would be so you know you've seen parts of how they've done three of these courses. If you were to decide I'm going to use, you know going to teach this course or if you were to have your ideal way of teaching it.
S: Mhmm
I: Using clickers what would suggest they do? So it seems like you would not want to have the points with the right answer.
S: Right. That's hard because they shouldn't [inaudible]
I: Yeah. What I mean of the other things you could decide what do you think would be good?
S: Probably um, I mean to make sure that you know you've gone over the material pretty thoroughly before you throw up the clicker question. Because otherwise I just kind of

feel, I mean me as a student I felt kind of lost. Because I don't know how to figure this one out yet because we haven't even really covered it.
I: Do you, so what do you do when you have that kind of question?
S: We just kind of, I just usually try to discuss it among a couple of people I'm sitting with or whatever. And…
I: Yeah. Do they (crosstalk). See things a bit different like oh. Does, I mean does that work.
S: Sometimes like yesterday we have one in chem.(Laughs) and I was sitting by this other guy and this girl and she was like oh yeah it's definitely c) because if you do this and this and that was definitely not the right answer (laughs) so. So sometimes it works to discuss it and sometimes it doesn't.
I: Yeah.
S: And sometimes I've met a (inaudible) and I'll think it's one and I kind of you know, go with my gut.
I: Yeah.
S: You know and then if I change it, it's like ah, you know I should have just stuck with what I felt the first time. (Laughs)
I: OK.
S: So. Plug in my answer. So.
I: Um, is there anything else that you'd like to say about the clickers or how they're used in the chemistry class?
S: Um, no, I mean I think overall they're a good learning tool. Definitely, because like I said especially if you've gone over the information then it just kind of lets it sink in more.
I: Yeah.
S: You know, so I think in that way they're definitely a good tool.
I: OK.
(Move on to the cognitive test)

Interview Transcript for "Edith" (FI Student)

I: Let's go ahead and start. Um, so what do you think about your chemistry class?

S: Um, there's too many students for the lecture hall.

I: Too many students?

S: Yeah, I'm sitting on the recycling bin.

I: You're sitting on the recycling bin?

S: Yeah, 'cause I have to run across campus in order to get there. And so I get into class and there's pretty much all seats are taken and I'm in the back, so. Right there something to sit on.

I: Yeah.

S: So far it's starting out kind of slow, cause I've chem. for awhile. I'm hoping it will pick up, the teacher seems kind of nice. Maybe a little overexcited at times, but better than boring.

I: Yeah. Uh, so what what do you think about the too many students? What do you…

S: I'm hoping that a lot of waitlisted in folk get booted out eventually, or just take decide to take it a different semester.

I: Is it mainly sitting on the recycling bin, or is there other aspects of the course size that…

S: Um, no it's mostly just lack of space, otherwise there's no interruption.

I: OK. OK. Um, I'm kind of going to be focusing on the clicker aspect. So how do you the clickers are used in the course?

S: In this particular class so far, in just two weeks of class, there have been several typos in the clickers, but that's not so much the clickers fault as much writing the clicker program.

I: OK

S: It seems to work fairly well. Just get an overall feel of how many people understand what's going on. Not much, just that. OK.

I: OK, ummm, when do you think the clicker questions are most effective?

S: Especially the conceptual kinds, because it's a little hard to say oh do this calculation in class, because we wanna use class time to not have to do that. But still need to judge when people know things.

I: OK. Ummm, have there been a lot of those, those hard calculations in class?

S: No. There have been minor calculations, most of them have been just fine.

I: Um, when you do the clicker questions, I know sometimes they have people talk with other people, do you often do that, or…

S: Yeah, very often. It's me and another friend from physics class, and we bounce questions off each other and see if we agree.

I: OK. SO do you just kind of automatically do that or do you think about it a bit first, or…

S: Mmm, yeah, I think about the question if I can try to figure it out on my own, and if I can't I ask ideas. I pretty much always verify my answer with another person.

I: Do you often, or do you ever change your answer based on.

S: Yes. Yeah.

I: Is it, is that a good thing or a bad thing?

S: Usually it's a good thing, not always. Depends how the other person is, and if they got it right and if they're convincing or not. Sometimes they might be very convincing with the wrong answer.
I: Um, I'm sure other people are talking as well. Have you ever kind of overheard some random stuff people say. Maybe not about, so I'm sure you can hear them saying I think B or C is the right answer. But do you ever hear people talking about just clickers in general?
S: Mmm, if there is any discussion that isn't about the question but is about the clicker, it's probably lack of batteries in the clicker or just small things like that, oh darn I forgot my clicker, it's running out of batteries, or oh darn I hit the wrong button.
I: OK, I, I um observed some classes last year and I often heard some kind of odd things people say. But I was kind of listening for that. We might, you know, come back to that later in the study. I'm just seeing if there's other things out there people see. Ummm, why do you think the professor is using clickers in the course?
S: It's a class of over 400 people, there's really not a better way to judge quickly if the majority of the students are understanding the material.
I: So you think that class size is important in…
S: Yes. I don't think that clickers are really needed in class sizes of 30. Those you can deal with hand raises and general discussion. But once you get more than 50 people it's just too much to deal with.
I: OK. More than 50?
S: Approximately. See my physics class is around 65 people and he used the clickers and it's small enough that we can ask questions, but for an overview it just isn't quite small enough to judge.
I: So you're you said you used them in your physics course. Are there other classes you've used clickers in?
S: All of my physics classes, and I'm trying to think if there were any others. No, my math classes haven't used it.
I: So, apparently a lot. So you've had a lot of physics.
S: Yeah, I'm a physics major, so I've had physics I, II and I'm in physics III right now.
I: Yeah. OK. Um, so so they've used clickers throughout these physics courses. How would you compare how they used them in physics to how they used them in your chemistry class.
S: Um, pretty similarly. Generally it's conceptual questions or very small arithmetic. And occasionally, just to see who's in class.
I: OK. Are they, um, about the same number of questions per class period?
S: It varies by professor. Cause I've had a different professor for all of my physics classes.
I: OK, so, OK.
S: Between like 2 and 6 clicker questions per hour. And that seems about normal.
I: OK. Do you think having more towards 6 is better or more towards 2 is better?
S: It depends on the lecture because if there are only 2 then we probably have been going over something on how to calculate something or difficult conceptual questions and then we need to just focus on one thing. But if there's a lot of things from one lecture then we can have multiple.
I: OK. Um, are they graded the same way?

S: It depends on the professor again. Usually you get a point for participating and then an extra point if you get the question right. And select questions might not get marked off for being wrong. And just however much, it's like either been the clickers count for extra credit or the clickers count maybe 5% of your grade. It's never been something significant. But it's enough to make you pay attention.
I: Which grading method do you think is, would be the one you'd prefer?
S: No preference really, as long as they have it organized well.
I: Um, I think you've kind of already kind of addressed this question already as far as understanding what it's about. So you often times people will put questions into categories so three categories I might talk about would be a recall question, an algorithmic question and a conceptual question. So do you know how you would think about the difference between those?
S: So algorithmic simple calculations figuring something out, conceptual, just knowing what's going on. Sometimes they word things to try to trick but it's no big deal, and then recalling is generally memorization: what's the equation, what's the name of that.
I: Yeah. What, how would you in your chemistry course, in your chemistry course how much do you think it would fit into each of those three categories?
S: Mostly conceptual and recollection so far, there's been some algorithmic but not much, it's so far just been percentages, which is not a big deal.
I: Um, which do you think is if you could say of those three types which do you think would be the best type of question?
S: There isn't really a best, depends on what we're learning that day. Just have to fit the clicker question to what the lecture has been.
I: Um, is there anything else about using clickers in chemistry you want to talk about?
S: chem. particularly, not too much.
I: How about in general?
S: Not too much. Although, I had one class where the professor could not get the clickers set up too well, but I think that he was kind of a bumbling old goof. There haven't been any other professors who had issues with it.
I: And it was used regularly in that class?
S: And I think he did the worst job of using them, but he was also a horrible lecturer in general.
I: What was the, what were the biggest problems you think in that class?
S: I think just being interested in the topics, so he didn't explain it well enough to know what was going on in the clicker question, so pretty much everyone ended up guessing, and that's not a really good way to judge any question or not.
I: Um, any other maybe criticisms of that class or other classes?
S: That class in particular was fairly horrible, nothing really with the clickers, that was the least of the issues.
I: OK.
S: Other classes, the clickers have been pretty well set for them. And already done and setup.
I: If, OK, let's talk about that one, the terrible class. If you could imagine that class taught without clickers, do you think, how do you think it would relate to the way it was?
S: It would still be just as bad.
I: So clickers didn't help it, didn't make it worse?

S: They didn't make it worse or better.
I: OK, it would have been bad either way?
S: Yes, absolutely. It was the experimental physics.
I: OK.
S: It was very dry lecture. So
I: I don't know, I don't know much about what goes on over there. I've heard, I've heard good and I've heard bad.
S: The physics are, the general physics classes have been amazing. The experimental, at least for that course of it, were abysmal.
I: OK. Is that a lab then?
S: Yeah. It's a lab and it has a lecture associated with it. Error analysis.
I: OK. That, that's hard to make interesting.
S: Yeah, but the professor made it worse. The second semester experimental, while it confuses the heck out of me, at least it's interesting now.
I: So you're doing, it seems like a lot of that would be doing experiments.
S: Yeah, a little. But that semester it was more along the lines of the error analysis and the MATHLAB reports, which didn't have anything to do with the labs so it was just the writeups and I got marked down heavily on all of those because they give you a four page sheet to learn to use MATHCAD and that's it. So don't really know how to use it and there expecting you to know how.
I: So it's um, did you like the experiment part of it?
S: The experiment part was decent. In general, at least.
I: Do you think, do you think the lecture part was inherently, there's no way to do it well, or…
S: There is a way to do it well. It's always going to be some fairly uninteresting material just because of what it is, but a good professor can make it far better, show applications of everything, explain it well, and then I think they could use the clickers to be (can't hear)
I: Were there, so, OK, in this experimental class were there a lot of, what was the class size on that when you had the lectures before it?
S: The lectures of it were I guess around 150, but.
I: But then you had separate labs?
S: Yeah. Those sections of maybe 20s, 30s, 40ish.
I: Um anything else on you want to share about clickers?
S: Clickers not too much, although it would be nice to have the identification number of them printed somewhere that it won't rub off.
I: OK. Ummm, so they have an ID.
S: They have an ID number on the back of them on a sticker.
I: So do you buy your own or is that?
S: You have to buy your own, but it lasts for any class as long as you have it.
I: SO if you lose the ID number you could mix it up with someone elses?
S: You could mix up with someone else's or like not be able to register it for another class.
I: Oh, 'cause you have to type it in.
S: I think so. I may have. It seems to vary.
I: OK.

S: Not positive.I don’t really, just have I got my clicker credit yet, and then if I haven’t then I fix it.
I: Um, anything else?
S: Not too much.
(introduce cognitive test)

APPENDIX D

HIDDEN FIGURE TEST

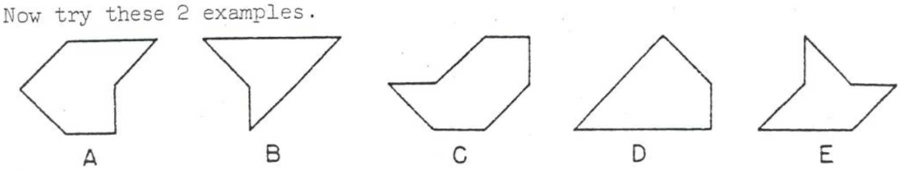
Name ______________________________

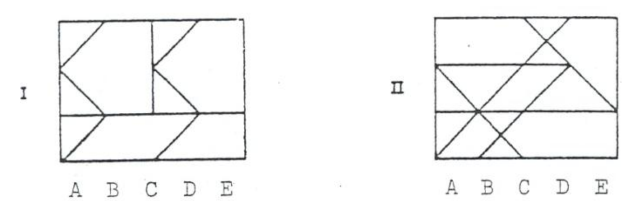
HIDDEN FIGURES TEST — CF-1 (Rev.)

This is a test of your ability to tell which one of five simple figures can be found in a more complex pattern. At the top of each page in this test are five simple figures lettered A, B, C, D, and E. Beneath each row of figures is a page of patterns. Each pattern has a row of letters beneath it. Indicate your answer by putting an X through the letter of the figure which you find in the pattern.

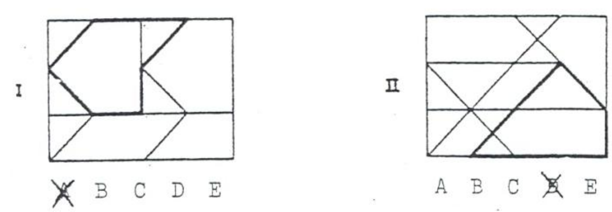
NOTE: There is only one of these figures in each pattern, and this figure will always be right side up and exactly the same size as one of the five lettered figures.

Now try these 2 examples.





The figures below show how the figures are included in the problems. Figure A is in the first problem and figure D in the second.



Your score on this test will be the number marked correctly minus a fraction of the number marked incorrectly. Therefore, it will not be to your advantage to guess unless you are able to eliminate one or more of the answer choices as wrong.

You will have 12 minutes for each of the two parts of this test. Each part has 2 pages. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.