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CLASSROOM RESPONSE SYSTEMS:
What Do They Add to An Active Learning Environment?

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CLASSROOM RESPONSE SYSTEMS:
What Do They Add to An Active Learning Environment?

by

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Dissertation

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Dedication

This dissertation is dedicated to my parents, who taught me to look beyond the horizon, and to my family who supports that quest.

Acknowledgments

Without the encouragement, guidance, and patience of my dissertation committee, and in particular Dr. Jill Marshall, this thesis could not have been written. Their kind direction helped me to understand the issues at hand more deeply. I also thank The Academy of Teacher Excellence at The University of Texas at San Antonio for their support and their willingness to provide feedback.

CLASSROOM RESPONSE SYSTEMS:

What Do They Add to An Active Learning Environment?

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This study investigated the impact of completely anonymous Classroom Response System (CRS) use on learning outcomes and student attitudes in a large university physical science course for pre-service teachers. As students were expected to have read the textbook prior to class, class time was devoted primarily to conceptual introductions followed by small group discussions of qualitative questions. In the treatment condition, each group provided a single response anonymously using the CRS. The control group responded individually and publicly by show of hands. Responses formed the basis for further discussion in both cases. Anonymity of responses in the control condition was expected to enhance participation and to provide more reliable formative assessment for the instructor, thus enhancing subsequent instruction and learning.

The overwhelmingly female study population comprised two course sections with the same instructor. The sections reversed treatment and control group roles for units on Newtonian mechanics and thermodynamics. Students took pre- and posttests for each unit, completed Response System Surveys once and the VASS twice, and submitted weekly mini-reflections and one metareflection. These were analyzed for evidence of attitudes toward science and learning. Whole-class discussions were video-recorded and analyzed for evidence of participation and use of student responses for "just-in-time" teaching.

Although CRS use did not improve learning outcomes over the control as measured by pre and posttests, it improved participation, as reflected in the video record and as self-reported by students in reflections, while it was in use. When they were using the CRS, students also indicated greater interest in learning for understanding, as opposed to preferring authoritarian delivery of information by the instructor and opportunities for procedural drills.

A framework for classroom interactions emerged. This "C^3" framework comprised three dimensions interacting on and through classroom conditions: concerns (performance goals to mastery goals), centeredness (teacher-centered to learner-centered), and control of discourse (traditional lecture to interactive dialogue). These apply to both instructors and students. In previous work, CRS use in classrooms was determined by instructors' positions on these three dimensions. Here, students shifted their centeredness and concerns based on how much the instructor shared the control of classroom discourse.

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Glossary

Acronym	**Title**
CATAALYST	Classroom Aggregation Technology for Activating and Assessing Learning and Your Students' Thinking
CRS	Classroom Response System
FCI	Force Concept Inventory
HPL	How People Learn
IKE	Internal Kinetic Energy
JiTT	Just-in-Time Teaching
NSF	National Science Foundation
PI	Peer Instruction
UT	The University of Texas at Austin
UTSA	The University of Texas at San Antonio
VASS	Views About Science Survey
WILD	Wireless Internet Learning Devices

CHAPTER 1

INTRODUCTION

This dissertation explores the impact of the completely anonymous and group-based use of a Classroom Response System (CRS) in a particular type of classroom setting: a discussion based, interactive introduction to physical science topics with frequent formative assessment implementation. Student responses to questions posed during class meetings formed the basis for subsequent instruction: in the CRS group, responses to focus questions were completely anonymous; in the control group, responses to the same focus questions were made by raising hands, and as such were completely public. Two topics in physical science formed the basis of evaluation: Newtonian mechanics and thermodynamics. The roles of treatment and control groups were switched between the two topics to have a measure of control between and within groups. All participants were undergraduate non-science majors in a pre-service teacher development program.

Traditional Physical Science Education

In the early 1990s, Sheila Tobias made an important statement that reverberated across disciplines: student success is in many cases hindered by the "disciplinary cultures" in place at institutions of learning. Furthermore, she suggested that there is no “magic bullet” that will solve all problems in mathematics and science education (Tobias, 1990; 1992). Even though over a decade has passed since these writings, change is slow in overcoming the inertia of traditional instructional models. Many physical science courses at universities across the country are taught in large lecture halls that were specifically designed to accommodate the old stand-by format of post-secondary education: the lecture. Professors stay near the lectern, delivering a monologue with the best intentions of providing students with a good grounding in the science they themselves love; they want to share the joy of discovery and understanding they have experienced along the way with a new generation of potential scientists. Yet, many of these professors are frustrated with students' low levels of motivation and with poor results on examinations. Where assessments go beyond the widespread testing of algorithmically based problem solving ability and venture into conceptually framed questions, faculty members often are even more discouraged. There is a "disconnect" between what the faculty member thought was so clearly communicated and what students understood (Arons, 1990; Bonwell & Eison, 1991; Halloun & Hestenes, 1985b; McDermott, 1993; Mestre, Gerace, Dufresne, & Leonard, 1997; Thornton & Sokoloff, 1990). This is not to say that the lecture does not work at all. Some students thrive on this format and are likely to continue their studies of science to receive advanced degrees in one of the disciplines. However, Edward F. Redish echoed the concern of many when he wrote in 1994:

> As physics teachers who care about physics, we have a tendency to concentrate on the physics content we're teaching. We often are most concerned for those students who are like we were – that small fraction of our students who find physics interesting and exciting and who will be the next generation of professional physicists. But the changes in our society and in the role of technology for the general public mean that we must change the way

> we are teaching. It no longer suffices to reproduce ourselves. Society has a great need not only for a few technically trained people, but for a large group of individuals who understand science. (Redish, 1994, p. 796)

Although it cannot be assumed that everyone has an innate need to understand the world in scientific terms, it can also not be assumed that only a very few individuals are predisposed to the learning of science. The issue then is that traditional science instruction indeed does not capture the interest of the majority of learners. This is especially unsettling when looking at who gets left out. As a recent publication by the National Science Foundation (NSF) shows, inequities in the distribution of degrees earned in fields of science, mathematics, and engineering are visible along lines of ethnicity and gender (National Science Foundation, 2004). Tables 1.1 and 1.2 below are adapted from the data collected by the agency.

Table 1.1: Distribution of Bachelor Degrees Earned in Fields of Science and Engineering, 1994 - 2001

Race/Ethnicity	1994 (%)	2001 (%)
White	78.0	69.7
Asian/Pacific Islander	6.9	9.5
Black	6.9	8.7
Hispanic	5.4	7.4
American Indian/Alaskan Native	0.5	0.7
Unknown race/ethnicity	2.3	4.1

SOURCE: National Science Foundation. (2004). Women, Minorities, and Persons with Disabilities in Science and Engineering (No. NSF 04-317). TABLE C-7. Field distribution of U.S.-citizen and permanent-resident bachelor's degree recipients, by race/ethnicity: 1994–2001. Race/ethnicity designators are identical to those used in the original publication.

Table 1.2: Bachelor Degrees Earned by Females in Physical Sciences, 1994 - 2001

Year	Physical Sciences (%)
1994	34.6
1995	35.5
1996	37.0
1997	38.5
1998	39.2
2000	41.1
2001	41.7

SOURCE: National Science Foundation. (2004). Women, Minorities, and Persons with Disabilities in Science and Engineering (No. NSF 04-317). TABLE C-4. Bachelor's degrees, by sex and field: 1994–2001. Only data included here are degrees earned by females in mathematics/statistics and physical sciences in percent and by year. Data for 1999 were not available.

Alternative Models of Physical Science Education

Non-lecture based learning models are neither particularly new, nor are they bound to a particular cultural tradition. For example, non-Western models are largely "community-based and communal in nature," emphasizing the role of language. There is "concern with the proper use of language, knowledge of the spoken traditions of the community, and the ability to [use] language creatively to reason and to argue are all powerful components of language use…" (Reagan, 2005, pp. 248-250).

Within the Western educational tradition, one need only consult the works of John Dewey and Lev Vygotsky to find strong arguments in favor of socially based learning models. John Dewey's 'pedagogical creed' (Dewey, 1897) begins with the statement that ". . . all education proceeds by the participation of the individual in the social consciousness . . .” Since this declaration is the first amongst his educational principles, it is a clear signal that he viewed learning primarily as a social event. Vygotsky also centers learning on social interactions, and posits that before individual cognitive growth, or ‘intrapsychological’ learning, comes the ‘interpsychological’ event of social learning (Vygotsky, 1978).

The recognition of the pitfalls of traditional science education led educators to develop approaches that are more aligned with the hallmarks of socioconstructive thought. Physical science classes are more-and-more frequently based on models such as ‘Interactive Engagement’ (Hake, 1998b) or ‘Peer Instruction’ (Mazur, 1997), and, although not necessarily linked to socioconstructivist methods, new technologies are embraced with the hope of improving learning outcomes for a larger part of the student population.

Classroom Response Systems

A typical CRS consists of transmitters that students use to send responses, receivers that collect these inputs, a computer, and software that interprets and aggregates these responses in real time. The instructor has a choice as to how publicly or how anonymously student input signals are collected, by showing either only that a certain transmitter has provided some input or by identifying the respondent by name, and sometimes even with the particular choice. Aggregated responses are almost always publicly displayed to inform both instructors and learners of the overall distribution of selections in a classroom. More inclusively defined are “Classroom

Aggregation Technology for Activating and Assessing Learning and Your Students' Thinking” (CATAALYST) systems (Roschelle, Abrahamson, & Penuel, 2004). This terminology grouping not only addresses the ‘voting machines’ described above, but also generative models which provide opportunities to capitalize on and foster the strengths of diversity in thought, learner agency, and participation within a playful exploration that expands the space in which learning occurs (Stroup, Ares, & Hurford, Draft; in press; Stroup et al., 2002). This study, however, was executed with and focuses on the ‘typical CRS’ only.

Although quite a few general investigations of CRSs are available (e.g., Burnstein & Lederman, 2001; 2003; Dufresne, Wenk, Mestre, Gerace, & Leonard, 1996; Meltzer & Manivannan, 2002; Mestre et al., 1997; Miller, Ashar, & Getz, 2003; Robertson, 2000), little research exists on specific uses of CRSs, the motivating potential of these tools, and their impacts on learning outcomes. Anecdotal reports of typical CRS use are much more frequent, such as for example an article just recently published in the Chronicle of Higher Education, a publication that is widely read across the fields of education (Carnevale, 2005). The instructor uses the system in purely individual mode, gives students 30-40 seconds per question to answer, and uses the input as part of the overall course grade.

A fairly recent comparison of several systems indicates that commercially available products are remarkably similar (Burnstein & Lederman, 2003). Amongst the most frequent uses of CRSs are collection of attendance data and of summative assessment data. Other common uses include collection of survey data regarding prior knowledge and student attitudes. Less frequent in the literature are uses such as purely formative assessment that serves to scaffold instruction, and none of the studies report results of classroom interactions where a CRS is used in complete anonymity. A more detailed discussion of CRSs follows in the literature review.

This Research Effort

The study at hand took place in a university-level physical science course for non-science majors, in traditional lecture hall with seating for 120 students. Instructional approaches consisted of short conceptual introductions, followed by small group and whole group discussions to provide opportunities for peer instructional segments, as well as ongoing formative assessment and feedback events. On average, discussions account for approximately 80% of class time. The treatment consisted of the completely anonymous use of a CRS for the collection of student responses to focus questions. To provide a control condition to the treatment, two topics in introductory physical science education were assigned to become treatment and control group content for two different sections of the same course in the same semester. One section was the designated CRS group for Newtonian Mechanics and the control group for thermodynamics, and the other section served the same functions in the reverse order. Both of the conceptual topics, Newtonian mechanics and thermodynamics, are taught as part of the standard curriculum, and both topics have been identified as problematic for learners. The details of setting and approach can be found in Chapter 3, titled “Method”.

Statement of the Problem

CRSs are used increasingly across disciplines and age groups. Yet, so far there is insufficient research on what constitutes optimal conditions of use. Reports generally address individual rather than small group use of CRSs, and compare non-CRS supported traditional practice with CRS supported interactive methodologies. There also are no reports of entirely anonymous response collection.

Logistical difficulties for instructors and added cost to students mean that the implementation of these systems must have a clear benefit to be worthwhile. The problem is further exacerbated by the fact that student populations are diverse and that some students react differently to the technology than others. Thus, it is not only necessary to explore different conditions of use in a particular setting, but to explore these conditions of use across diverse settings. This study was completed with a population of pre-service students, most of whom are Hispanic or White females.

The two central questions in this study are: (1) In terms of learning outcomes, is complete anonymity in the use of a CRS beneficial compared with public responses by raising hands when combined with an interactive classroom practice of small and whole group discussion that is informed by ongoing formative assessment? (2) What impact does such use have on student attitudes?

To answer these questions, related subordinate questions are addressed. These are listed in Table 1.3 below, each aligned with the instruments used to evaluate that aspect.

Table 1.3: Subordinate Research Questions and Instrumentation

Research Question	**Instrument**
1. Does complete anonymity inform subsequent instruction in ways that will improve learning outcomes?	Video- and audio analysis; Pre- and posttest
2. To what degree do formative assessment questions influence learning outcomes?	Pre- and posttest; CRS in-class response data
3. Does this type of instruction change student attitudes towards the learning of science?	Views about Science Survey (VASS); CRS Survey; Meta- and Weekly Reflections

Summary

Dissatisfaction with traditional classroom models has led to the development of alternative and more interactive instructional methodologies, including those that employ CRSs to increase active participation on the part of students. As the frequency with which CRSs are used in classrooms is increasing, it becomes more and more important to define the affordances and limitations of these tools. The following chapters will first situate this research effort in terms of existing literature (Chapter 2), and then describe the methodology (Chapter 3) and results (Chapter 4). A summary and discussion (Chapter 5) offers the author's interpretation of results and is followed by conclusions and implications for future research (Chapter 6).

CHAPTER 2

REVIEW OF RELATED LITERATURE

Introduction

This chapter provides a review of the different strands of research literature that inform this study. Since learning occurs in a highly complex set of interactions of both inter- and intrapersonal nature, many facets of learning research provide valuable insights into the classroom interactions this research is based on. This chapter is organized into sections that will situate the effort in terms of CRS and non-CRS literature.

Classroom Response System Literature

Aspects of CRS use are discussed in education literature and in other publications, such as in business contexts or in newspapers (English, 2003; Hafner, 2004; Horowitz, 1988). However, for the purposes of this study only educational research articles are considered in this literature review.

A recent analysis of 26 classroom network studies by SRI and Better Education researchers Jeremy Roschelle, Bill Penuel, and Louis Abrahamson indicates that there is good agreement in terms of benefits of use (Roschelle, Abrahamson et al., 2004; Roschelle, Penuel, & Abrahamson, 2004). Specifically, they found indications of "greater student engagement (16 studies), increased student understanding of complex subject matter (11), increased student interest and enjoyment (7), heightened discussion and interactivity (6), increased student awareness of individual levels of comprehension (5), and increased teacher insight into student difficulties (4).” However, their review also indicates that the studies lacked in rigor, making it impossible to draw strong conclusions about the technology’s effectiveness.

In preparing for the current study, the author also researched existing CRS literature for commonalities in findings. Some of the studies included here are part of the 2004 meta-analysis as well; however, the basis of comparison is a different one to complement rather than duplicate the findings above. A total of 30 publications were initially categorized based on main focus: (a) general overview of either existing technologies or conditions of use; (b) pedagogical theory; (c) reports on implementation studies (Table 2.1 below).

Table 2.1: CRS Publications – Focus

Focus	Articles
General overview (8)	(Abrahamson, 1998; 1999; Beatty, 2004; Burnstein & Lederman, 2003; Penuel, Roschelle, Crawford, Shechtman, & Abrahamson, 2004; Robertson, 2000; Roschelle, Abrahamson et al., 2004; Roschelle, Penuel et al., 2004)
Pedagogical Theory (8)	(Crouch & Mazur, 2001; Dufresne, Gerace, Leonard, & Mestre, 2000; Fagen, Crouch, & Mazur, 2002; Mazur, 1997; Motani & Garg, 2002; Roschelle & Pea, 2002; Stroup et al., Draft; Stroup et al., 2002)
Implementation Study (14)	(Boyle, 1999; Bullock et al., 2002; Burnstein & Lederman, 2001; Cue, 1998; S. M. Davis, 2003; Dufresne et al., 1996; Ganger & Jackson, 2003; Hall, Waitz, Brodeur, Soderholm, & Nasr, 2002; Mestre, Gerace, Dufresne, & Leonard, 1996; Nicol & Boyle, 2003; Paschal, 2002; Poulis, Massen, Robens, & Gilbert, 1998; Reay, Bao, Pengfei, Warnakulasooriya, & Baugh, 2005; Woods & Chiu, 2003)

General Overviews

Included in this category are meta-analyses of CRS literature, general recommendations of use, and technical descriptions and comparisons. As part of providing an inventory of what is known of CRS use, these publications report benefits and shortcomings of CRS supported instruction in terms of instructor and learner attitudes, instructor sensitivity to learner understanding, and learning outcomes. However, in almost all instances reported, comparisons are made between traditional lecture conditions and CRS supported classrooms that, in addition to the technology component, also adopted interactive methodologies. Exceptions are research reports from the University of Massachusetts at Amherst (Mestre, Gerace, Dufresne, & Leonard, 1996), and the University at Strathclyde in Great Britain (Nicol & Boyle, 2003), who each compared two types of interactive instruction, one with and one without a CRS. Mestre et al. found that, while the use of the CRS is not necessary, the histogram generated by the system software, in and of itself, promotes discussion. In their classrooms, students often addressed the answer option chosen by the majority first. Nicol and Boyle indicate that students preferred peer instructional segments over whole-class discussions, and that they thought of the latter as easily confusing.

Burnstein and Lederman (2003) compared traditional CRSs in terms of functionalities and found that they are remarkably similar. However, the range of possibilities is not limited to these systems. Next-generation systems such as the TI-

Navigator, or handheld technologies such as PDAs go beyond the typical "pick the correct answer" type of voting where learners select a multiple-choice option. Poulis et al. (1998), on the other hand, used a system that has only one single button to indicate agreement. In this case, each answer option of a multiple choice question was asked separately. This system may be of advantage in a recently proposed 'enhanced multiple choice type questions' approach. (Burnstein & Lederman, 2005) Here, the number of answer options is greater than the traditional four or five, and, aside from one correct option, there are partially correct options as well.

Abrahamson (1999), Beatty (2004), and Nicol and Boyle (2003) point out that hand-held technologies are ideal to support interactive learning environments, rather than tools that improve learning conditions regardless of pedagogical context. As such they are considered to be catalysts for improved learning – a characteristic that SRI and Better Education Foundation researchers (Roschelle, Penuel, and Abrahamson) based their acronym for the wide variety of CRS on: CATAALYST. Included in CATAALYST technologies are traditional and next-generation models, some of which were developed from within educational contexts, such as classroom response systems or calculators, and others that were designed with a focus on non-educational applications, such as PDAs.

Almost all of the studies included in these general overview articles were based on purely individual use of CRS. That is, although students may or may not have had opportunities to talk with peers, they ultimately made individual selections.

Exceptions to this pattern are the research by Mestre, Gerace, Dufresne, and Leonard at the University of Massachusetts, where responses are elicited in three different modes: individual, group, and group with dissent; and trials by Reay et al. (2005) at Ohio State University as well as by Boyle (1999) which include both group and individual response opportunities. Reay et al. compare one semester of group-based voting with a second semester of individual voting and found that students enjoyed group discussions, but some voiced concerns about 'group experts' dominating the discussion. In addition, although there were fewer complaints in the individual use semester, the percentage of students voting decreased.

Pedagogical Theory

This set includes CRS literature that ranges from considerations of a specific pedagogical construct, such as the timing of feedback (Motani & Garg, 2002), to literature that reaches beyond considerations of affordances and limitations in traditional CRS to possibilities of next-generation systems (Penuel et al., 2004; Roschelle & Pea, 2002; Stroup et al., Draft; Stroup et al., 2002).

The intent of Mazur's group at Harvard and Dufresne's in Massachusetts, is to make classrooms more interactive and students more active participants in their own learning processes (Dufresne et al., 1996; Mazur, 1997). However, their discussion sequences are somewhat different. In Mazur's Peer Instruction, the initial stage consists of individual responses which are followed by small group discussion and then a second response; Dufresne's model first has students discuss in small groups and then vote either individually or as groups.

Mazur's Peer Instruction (PI), although not specific to CRS classrooms, benefits from the technology through its support of instantaneous feedback. Before the use of CRS, Mazur asked students to respond for example by holding up signs with the answer option of their choice (p. 17). However, getting an accurate count of the distribution of these choices was difficult in a large lecture class. Since CRSs provide reliable aggregation of inputs and immediate, easily interpretable output in the form of a histogram, this technology greatly facilitates the use of student feedback. Yet, the author points out "that the success of Peer Instruction is independent of feedback method and therefore independent of financial or technological resources" (p. 18). Subsequent work on the effectiveness of PI includes instructor surveys administered by the Mazur group (Crouch & Mazur, 2001; Fagen et al., 2002). Results indicate that student engagement and learning outcomes are both improved.

Dufresne et al. (1996) developed a CRS supported instructional cycle that is based on Kolb's Experiential Learning Cycle and relies heavily on the instantaneous feedback aggregation. Much like Mazur's Peer Instruction, these researchers rely on student-student interactions in small group settings and alternate these with whole-class evaluations. The conceptual discussion follows a cyclical path in that the discussion of one question tends to naturally lead to an exploration of a related question. While instructors come to class with certain pre-planned questions, it is ultimately the class as a whole that determines which questions get asked and discussed.

Stroup et al. are engaged in research on next-generation functionalities that open the learning space, thus broadening the possibilities for discoveries in a socioconstructivist sense. The contributions of participants direct the particulars of a given classroom conversation and thus the overall picture that emerges; content and social interactions simultaneously act upon each other. This kind of interaction is thus highly generative by design. The research group also developed a taxonomy of generativity that places different types of CRS along a continuum (Stroup et al., Draft). At one extreme is the nominally generative 'right/wrong' discussion of fairly traditional teacher-centered lecture formats, where there is a single correct response and a single correct pathway to find it; at the other extreme is the highly learner-centered emergent group activity, where individual learners become contributors to an overall group behavior that then becomes the subject of analysis.

Bridging the span between CRS generations is the article by Roschelle and Pea (2002) who describe not only current conditions of CATAALYST technologies, but also considerations for the future. They use the term Wireless Internet Learning Devices (WILD) to address handheld technologies. Roschelle and Pea suggest that these low cost and highly portable devices offer ideal support for classroom methodologies that follow theories of distributed intelligence or distributed cognition (p. 151).

Although listed with the ‘general overview’ segment, the 2004 CATAALYST workshop report by Penuel et al. also fits this section as they note that existing learning theories and research models may not be sufficient for these technologies (pp. iii, 10-11).

Implementation Studies

This section includes only studies that report on classroom instantiations of CRS use. First a brief summary of where and how data are collected: All but three European (Boyle, 1999; Nicol & Boyle, 2003; Poulis et al., 1998) and one Asian report (Cue, 1998) are based on U.S. classrooms. Most of the articles report findings in undergraduate physics courses; exceptions are two medical (Ganger & Jackson, 2003; Paschal, 2002), three engineering (Boyle, 1999; Hall et al., 2002; Nicol & Boyle, 2003), and one high school mathematics study (S. M. Davis, 2003). The report by Woods and Chiu (2003) is based on classroom experiences in both physical science and life science courses. This bias towards studies in physical science is only partially due to the author’s teaching in the same discipline; it is largely a reflection of existing CRS literature.

These publications were also categorized in terms of types of data collected in order to better understand methodologies in use (Table 2.2).

Table 2.2: CRS Publications – Data Types Collected

	survey	interview	questionnaire	reflection	observation, field notes	test results
Bullock et al., 2002		X	X			X
Cue, 1998	X					
Davis, 2003		X			X	
Dufresne et al., 1996		X	X		X	
Ganger & Jackson, 2003	X					
Hall et al., 2002	X			X		
Mestre et al., 1996	X					
Nicol & Boyle, 2003	X	X	X			
Paschal, 2002	X					X
Poulis et al., 1998	X					
Reay et al., 2005	X					X
Woods & Chiu, 2003	X					

By far the most frequently used form of data collection is surveying. However, often these data are combined with other types to understand the learning context more deeply. Interestingly, reflections were used in only one of these studies.

Some of the findings in these studies show good agreement, others are mentioned only once (see Appendix A: Table of CRS Implementation Studies). What follows is first a discussion of fairly universal findings, then those that are less frequently reported.

As mentioned earlier in this chapter, the review of CRS literature points to overwhelmingly individual use. Even in cases where there are small group discussions, these are followed up with individual response collections. These responses frequently are counted toward course grades, using a 'staggered' point system where students may still receive partial credit for incorrect selections (Burnstein & Lederman, 2001; Crouch & Mazur, 2001; Cue, 1998; Paschal, 2002; Woods & Chiu, 2003). Although the intent is to motivate participation by offering a reward for trying, this practice may lead to difficulties in interpreting data: Amongst the most commonly stated benefits of CRS use are improved attendance and participation, which may to some degree be attributable to the practice of making part of the course grade dependent upon CRS input.

As also stated in the general overview literature cited earlier, most frequently reported benefits of CRS include more interactive, more engaging, and more enjoyable class meetings in which both instructors and students become more aware of the condition of the students' understanding, and which ultimately lead to better understanding. In addition to the studies included in the review of SRI and Better Education researchers (Roschelle, Abrahamson et al., 2004; Roschelle, Penuel et al., 2004), some or all of these benefits were also reported by Bullock et al. (2002), Davis (2003), Hall et al. (2002), Mestre et al. (1996), and Paschal (2002). Several studies emphasized responsive teaching practices based on student feedback (Bullock et al., 2002; S. M. Davis, 2003; Dufresne et al., 1996; Hall et al., 2002). Hall et al. indicate that students perceive instructors who teach in a responsive manner as 'caring'.

Additional findings, although less universal, are of equal importance in making pedagogical decisions. Several studies included student ratings of small group discussion components. Nicol and Boyle (2003) found that students preferred small group discussions over whole group discussions, arguing that whole class discussions became confusing more easily. Reay et al. (2005) report that students ranked these discussions as the most important part of the CRS interaction. However, when given a choice between individual 'voting' and group choice, students preferred to use the CRS in individual mode.

As Davis (2003) and Nicol and Boyle (2003) point out, the systems' ability to provide anonymous participation with private accountability is a critical feature of CRSs. Students are free to provide input without the fear of possible public humiliation, and without having to worry about more vocal students dominating the discussion. As Davis further reports, this 'empowering' ability of the CRS is limited to the period of use and does not continue to be effective in later, non-CRS aided sessions. Both Dufresne et al. (1996) and Nicol and Boyle (2003) hint at the uncertainty of effect size of this technology by stating that improvements cannot be ascribed to the CRS alone, but are also due to changes in the overall pedagogical approach.

The CRS literature recognizes that it is not enough just to add one of these systems to existing classroom practice. They are technological tools, no more and no less. Their benefits only become realized if coupled with appropriate pedagogy (e.g., Abrahamson, 1999; Abrahamson, Owens, Demana, Meagher, & Herman, 2003; Beatty, 2004; Dufresne et al., 2000; Mazur, 1997; Penuel et al., 2004; Roschelle, Abrahamson et al., 2004). If used appropriately though, they align very well with the constructs of centeredness as described in “How People Learn” (Bransford, Brown, & Cocking, 2000).

Some of the shortcomings of CRSs are technological in nature. For example, signal degradation or software malfunction have negative consequences for all parties involved. Depending on which system is implemented, cost may be another factor to consider. Although systems that are adopted in tandem with textbooks are usually very inexpensive for the institution, the cost for site licenses and hardware may range in the thousands of US dollars. The fact that CRSs are often solely used to collect attendance and summative assessment data may be linked to publisher sponsored CRS information sessions emphasizing administrative aspects. However, some instructors indicate that it is precisely these administrative aspects that cause them to reconsider use of a CRS. For example, they identify student registration and record management as cumbersome, and struggle with accommodations for students either forgetting to bring transmitters altogether, or for batteries running low. A common frustration voiced by instructors who use CRSs is that set-up and break-down time take up too much of the class period (Fies & Marshall, 2005).

For students, a considerable disadvantage of one-way systems is that each participant has to find his or her transmitter identifier on the screen to verify that the receiver in fact has recognized and read the signal. If used in groups, group dynamics may get in the way of learning for individuals. For example, if one partner needs a little more time to think before discussion, it is frustrating to hear the other partners already talking about the question (Dufresne et al., 1996). However, this particular issue is germane to all group-based learning models and as such not particular to CRSs.

An important limitation for faculty members is that questions can only be asked in either true/false or multiple-choice format (Burnstein & Lederman, 2003). However, the need to carefully craft meaningful conceptual questions forces the developer to focus on what the salient conceptual issues are (Dufresne et al., 1996; Fagen et al., 2002; Hestenes, Wells, & Swackhamer, 1992; Kraus & Minstrell, 2002; Mestre et al., 1996; Reay et al., 2005). Yet, since the typical CRS is technologically limited to objective questions, the possible outcome is narrowed to a single, pre-determined endpoint. As such, all of the typical paper-and-pencil limitations of objective question formats apply. For example, learners may misinterpret the question stem and/or answer options regardless of how clearly the question developer thought the wording was put. In the case of formative assessment, there is an immediate opportunity to discuss different interpretations of the question and to thus enrich the conceptual understanding. In the case of summative assessment, students are exposed to a stressful high-stakes guessing game.

The C^3-Framework

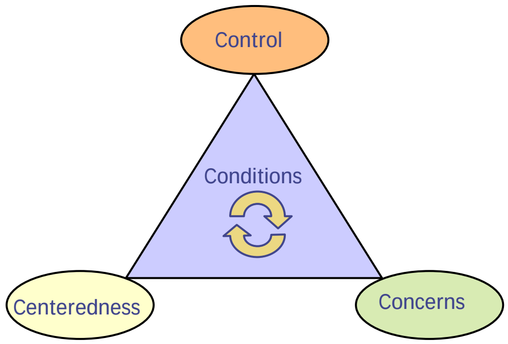
How CRSs are used in a particular classroom and at a particular time depends greatly on the interplay of the instructor's pedagogical beliefs, the students' willingness to 'play by the instructor's rules,' and the technology itself. This became apparent in preparation for this thesis, when the researcher conducted a preliminary study during the spring of 2004 (Fies & Marshall, 2005). The qualitative study followed the model of Grounded Theory (Strauss & Corbin, 1998) and was designed to explore the extent and types of CRS use across disciplines, as well as to investigate whether these systems do change classroom practice.

The study triangulated three types of data elements collected at UT and UTSA: Semi-structured interviews with faculty members, classroom observations, and student surveys that in part already existed at UT, and in part were gathered at UTSA. All of the participants came from disciplines in the colleges of science, engineering, computer science, and business. Faculty data were gathered in six classroom observations and seven faculty interviews. Student data that pre-existed at UT were provided by a large sample of 1397 participants; student data collected at UTSA during the spring of 2004 was submitted by 153 participants.

After triangulating the different data types and sets, the picture that surfaced was one that has been seen before. The mere introduction of a new curricular tool does not necessitate curricular change. When the computer was introduced into schools in the 1970s, the general expectation was a substantial change in educational practice. Yet, the system itself changed the possibilities of the tool, rather than the tool changing the possibilities of the system (Papert, 1997; Windschitl, 2002). That is, rather than using computers to innovate classroom interactions, they were subordinated to traditional models. CRSs currently in use at UT and UTSA are flexible and are also adapted and incorporated into existing practice rather than effecting a change in the system.

The C^3 framework that emerged in regards to how faculty members implement the use of a CRS consists of a triangular relationship of Concerns, Centeredness, and Control of the classroom discourse (Figure 2.1).

Figure 2.1: C^3 Framework



The interactions between the three dimensions describe the conditions of use in the classroom. Although these are mutually influencing and being influenced by each other, control of the classroom discourse is fed more by the other two dimensions than it feeds them. The extremes of the Concerns dimension align with performance and mastery goals as described in motivation theory (e.g., Ames & Archer, 1988; Elliott & Dweck, 1988; Murphy & Alexander, 2000; Pintrich, 2000; Wentzel, 2000). That is, performance goals are procedural in nature and include for example concerns about gathering attendance data, while mastery goals are learning outcome oriented.

The Centeredness dimension aligns with the model of centeredness as described in “How People Learn” (HPL) (Bransford et al., 2000). The four HPL dimensions are centeredness in terms of learner, community, knowledge, and assessment. That is, under ideal conditions instruction is sensitive to and begins with the learner’s prior knowledge and needs, continuously assesses in a formative manner what the understanding of a given concept is, and is community based.

Control of discourse then is influenced by the instructor's position on both the Concerns and Centeredness dimensions. That is, an instructor with a heavy emphasis on performance goals who has a prepared lecture from which s/he does not intend to deviate will prefer complete control over the direction of discourse – in practice most likely a monologue. On the other hand, an instructor with an emphasis on mastery goals who is interested in what students think is more likely to share control over the discourse and the direction of discussion.

Non-CRS Literature

This part of the literature review will address the following components of non-CRS specific literature: issues in assessment, participation, and in cognition. Each of these aspects informs how CRS use may influence learner attitudes and learning outcomes, and each provides a background against which the technology's effects can be interpreted.

Assessment

At the most general level, assessment can be broken down into summative and formative practices. Summative assessment can be considered to be 'end-loaded', while formative assessment is 'front-loaded'. That is, summative assessment is a graded evaluation of student learning that takes place at the end of an instructional component, and that typically is not followed by corrective measures. Formative assessment, on the other hand, takes place in the process of learning and thus offers opportunities to provide constructive feedback and clarifying measures. Of interest here is formative assessment as it scaffolds the learning process in a socioconstructivist manner (Puntambekar & Kolodner, 2005).

The need for ongoing and formative assessment is clearly established in the literature. The following quote is taken from the "Seven Principles for Good Practice in Undergraduate Education:"

> Knowing what you know and don't know focuses learning. Students need appropriate feedback on performance to benefit from courses. In getting started, students need help in assessing existing knowledge and competence. In classes, students need frequent opportunities to perform and receive suggestions for improvement. At various points during college, and at the end, students need chances to reflect on what they have learnt, what they still have to learn, and how to assess themselves. (Chickering & Gamson, 1987)

This sentiment is echoed in the statement that the "point is to monitor progress toward intended goals in a spirit of continuous improvement" (American Association for Higher Education (AAHE), 1992). HPL also makes a strong case for the need to provide ongoing assessment, and ascribes it the status of one of the four dimensions of centeredness (Bransford et al., 2000). A stated challenge in developing and implementing meaningful assessment methods lies in beliefs of what effective learning is: recall of memorized facts, or application of understanding (p. 141). Critical are not only the beliefs of the instructor, but also institutional beliefs, and those of the students themselves.

Formative assessment fulfills a dual function: it provides the learner with opportunities to discover instances of conflict, and it provides instructors with opportunities to recognize what problematic conceptions might be present in the classroom. Once the teacher is aware of ideas learners hold regarding a specific concept, it is possible to adjust subsequent instruction to the learning needs of the group at that particular place and time. This nicely aligns with the Just-in-time teaching (JiTT) stance (Novak, Patterson, Gavrin, & Christian, 1999).

The origins of the 'just-in-time' approach lie in the business community (http://en.wikipedia.org/wiki/Just_in_time). There, materials are re-ordered 'just-in-time' to minimize cost for warehousing. In education, 'just-in-time' is an approach where information is provided as the need for it arises within the learners themselves (Schank, 2002). That is, it is ideally responsive to student understanding of a concept at a particular time and place. There seem to be two possible ways of how this idea may be playing out: (1) the industrial model is directly supplanted to education, but remains essentially intact. Here teachers are somewhat disenfranchised intermediaries who provide the learner only with information as requested; this seems to cast the teacher in the role of an on-demand supplier and requires learners to be savvy in terms of identifying what they need and when they need it. (2) An educational model in which the teacher uses formative assessment as the basis for subsequent instructional decisions. Thus the basis for decisions still is the learners' need, but here a skilled facilitator provides scaffolding as necessary. The latter is in line with the concept of just-in-time teaching, where students are asked to complete preparatory work that informs the instructional sequence (Novak et al., 1999; Novak, Patterson, Gavrin, & Enger, 1998).

Whether students are taking state mandated tests, national tests, or regular in-class assessments, chances are that the questions they answer fall into one of three categories: multiple choice, true/false, or matching. These “objective” items are easily scored, but tend to say preciously little about what students think. Students frequently are unable to identify the ‘correct’ response, even when they understand the concept asked; what they do not necessarily understand is the wording of the question. Notable exceptions are diagnostic tools such as the Force Concept Inventory (FCI), which was developed in response to a demonstrated lack of conceptual understanding amongst learners of introductory mechanics courses (Hestenes et al., 1992), or the facet-based Diagnoser system (Kraus & Minstrell, 2002; Minstrell, n.d.). Facets are rated in terms of how problematic they are in comparison to the accepted view of the concept. These questions use identified alternative conceptions as distractor items and thus inform the instructor of which naïve understandings need to be addressed in subsequent instruction. Other question research is focused on the development of question systems with carefully sequenced sets of questions (Reay et al., 2005; Rollnick & Mahooana, 1999). Reay et al. develop three-question sequences on a given concept, yet with different surface features. The first question serves as a warm-up and confidence builder, the second is more difficult, the third tests for depth of understanding by asking about the concept with very different surface features. Each of the questions is followed by discussion and voting segments.

In summary, the literature on assessment supports the hypothesis that CRSs will improve learning over the use of a show of hands because this technology allows for more precise and complete formative assessment and thus, in theory, more effective JiTT. By contrast, this literature also suggests that careful construction of the questions and distractors used with the CRS may be required in order for it to be effective.

Participation

As mentioned before, participatory learning environments are not new and exist in low and high technology contexts, and the research literature defines well both the extent and conditions of participation in general learning contexts (e.g., Bransford et al., 2000; Greeno, Collins, & Resnick, 1996; Lave & Wenger, 1991; Salomon & Perkins, 1998; Slater & van Aalst, 2002). Daniel Hickey contrasts engaged participation with marginal nonparticipation in an effort to contextualize motivation in learning environments (Hickey, 2003). The interaction between individual and social spheres are interpreted to lead either to an inwards-bound trajectory in the sense of legitimate peripheral participation (Lave & Wenger, 1991), or an outwards-bound trajectory that increasingly leads to marginalization and ultimate separation.

When the teacher asks a question of the class as a whole, most frequently only a few of the students are willing to take the risk of publicly taking a stand on that issue. Those students are usually either those who are certain that they know the correct response, or those who are blessed with a rather highly developed sense of self-confidence – regardless of whether they do or don't know the 'right answer'. Either way, the instructor will only get to hear from a very few of the students.

Sometimes instructors will try to remedy this situation by asking all of the students to answer the same question, one after another. Although this results in everyone saying something, the quality of the exchange is not necessarily improved. The larger the number of students, the more "tuning-out" still occurs, and later responses are increasingly likely to repeat earlier ones. One of the critical problems with this pattern is that students who find out they publicly made an incorrect statement may feel embarrassed and opt to avoid overt participation in future discussions. Participation problems appear to be ubiquitous as they are for example also found in professional workshops in other fields (Horowitz, 1988). As indicated by the CRS literature, students are more likely to contribute to a classroom interaction in ways that allow them to remain anonymous. There is safety in anonymity, but, yet, anonymity is a 'two-edged sword.' Especially the anonymity students tend to experience in a large lecture hall is thought to be detrimental to learning and to be a major factor contributing to high attrition rates (McKeachie, 2002). Specifically, research shows students who "are anonymous feel less personal responsibility – a consequence not only damaging to morale and order but also unlikely to facilitate learning." (p. 230)

Dreyfus proposes that anonymity is more than a mere detrimental factor, but rather a cause of insufficient learning outcomes (Dreyfus, 1998). Referring to Kierkegaard's writings, he draws parallels between the effects Kierkegaard perceived the press to have had on the readers, and the effects Dreyfus perceives the Internet to have on individual development. The stated common denominator is accountability: anonymity results in a lack of commitment since it is not necessary to take a public stand and to thus put oneself at risk of public failure. This idea serves as the rationale for Mazur's requirement that students initially respond individually: the act of public selection does require personal commitment, taking a stand, on the issue at hand (Mazur, 1997). Yet, Jessup et al. found that "Group members whose contributions were anonymous generated more comments, were more critical and probing, and were more likely to embellish ideas proposed by others than were those whose contributions were identified by name." (Jessup, Connolly, & Galegher, 1990)

Asking students to vote by show of hand puts them on the spot. There tends to be a 'silent majority' in classrooms when voting has to be done publicly. Yet, students willingly push a button on a CRS transmitter, knowing that neither their peers nor, in some cases, the instructor will know if they selected an incorrect choice. As mentioned in the CRS literature section, Davis (2003) found that a generative networked system supported participation in a way that did not transfer to the classroom interaction after use of the system. The community building effects that supported participation and lead to lively and deep discussion were not maintained during times in which the system was not used (p. 303).

Both participation and anonymity also influence aspects of agency. The awareness of having a voice, of being at least partially in control, and of being able to make a difference is an important emancipatory condition. Work with participatory simulations supports the claim that this technology can support the development of greater agency through providing the safety of greater anonymity (S. M. Davis, 2003; Stroup et al., 2002).

Calls for more active student participation recognize that the traditional 'one-way' delivery of traditional lectures is an ineffective model. Physics educators have developed active learning strategies such as Interactive Engagement (Hake, 1998a). Although socioconstructivist learning models have been accepted as valid pedagogies for decades, most classroom interactions still are driven by conservative practices rooted in the idea of knowledge transmission. This should be especially surprising given that social interaction, at the core of Vygotskian learning environments, is in fact the primary mode of communication in many non-school contexts. Thus it cannot be assumed that lecture-based instruction is the natural outgrowth of personal experiences outside of formal schooling.

McKeechie (2002, p. 146) makes the following observation: "We can also consider cultural or gender-related issues that may affect class discussion. Many female students or students of both genders from American Indian or Asian-American backgrounds have been socialized to value listening more than speaking." This view is supported in HPL where the argument is made that some cultural variations "are more likely than others to encourage development of the specific kinds of knowledge and interaction styles that are expected in typical U.S. school environments" (J. D. Bransford et al., 2000, p. 109). The claim is not that any of these variations are more or less valid than others, but that the educational system is narrowly selecting specific modes of interaction that do not tap into the richness of the many ways of knowing and learning. The article goes on to identify 'four patterns of border crossing' that range from congruent to highly discordant worlds of home and school (p. 472). Further literature review shows that differences in academic progress on the basis of gender and ethnicity exist across the fields (e.g., C.-S. Davis et al., 1996; Ginorio & Huston, 2001; Hsi & Hoadley, 1997; Hulton & Furlong, 2001; Rassen, 2002; Riding & Grimley, 1999; Rosser, 1995; Stormquist, 1997).

An additional observation on gender-based differences in discourse participation is of interest here: A recent study of discourse patterns indicates that not only do men seem to be more comfortable with public debate-like discussions, but that females monitor the frequency of their public contributions:

> Students who speak frequently in class, many of whom are men, assume that it is their job to think of contributions and try to get the floor to express them. But many women monitor their participation not only to get the floor but also to avoid getting it. Women students in my class tell me that if they have spoken up once or twice, they hold back for the rest of the class because they don't want to dominate. If they have spoken a lot one week, they will remain silent the next ... (Tannen, 2004, p. 206)

The observation of female hesitance to speak in large groups is also expressed in a Swedish study (Benckert, 2001): "Women are often silent in large groups such as in classrooms. In small cooperative groups they get a better chance to speak and to participate in the discussions" (p. 5).

In summary, the literature on participation supports the hypothesis that anonymous use of CRS will be more effective in terms of promoting participation, and thus learning, over a public show of hands, particularly for female students. On the other hand, some voices in the literature raise concerns that the loss of accountability with completely anonymous use will have a detrimental impact.

Cognition

CRSs serve a motivating function; they may also provide a means for students to become more metacognitive learners as they evaluate and develop their own understanding in large lecture classes.

Byrnes states that motivating environments include goals, knowledge of how to attain these goals, and metacognitive aspects, such as monitoring of progress, appraisal of actions, as well as appraisal of outcomes (Byrnes, 2001). Goal theories distinguish for example between performance and mastery goals, and ascribe process focus to performance goals, and deep understanding of the concept to the mastery goals (e.g., Ames & Archer, 1988; Dweck & Leggett, 1988; Elliott & Dweck, 1988; Wentzel, 2000). Classrooms in which memorization and drill-and-practice are emphasized foster performance goal thinking; classrooms in which understanding and application are prioritized address mastery goals.

Motivation that is extrinsic in nature comes from rewards that others will give, such as good grades, or the promise of profitable employment opportunities. More aligned with mastery goals is the idea of intrinsic motivation.

> The will to learn is an intrinsic motive, one that finds both its source and its reward in its own exercise. The will to learn becomes a 'problem' only under specialized circumstances like those of a school, where a curriculum is set, students confined and a path fixed. (Malone & Lepper, 1987)

Intrinsically motivated students with mastery goals have a strong need to understand, and engaging classrooms are much more successful than traditional settings at fostering such learning behavior (e.g., Greeno et al., 1996; McKeachie, 2002; Pintrich, 2000; Ryan & Deci, 2000; Schunk, 2000). Interactive classrooms provide that kind of engaging environment, but at the same time may be stressful for some of the students due to the threat of public failure. A partial solution is to offer small-group conversations (Benckert, 2001; Seetharaman & Musier-Forsyth, 2003). Shyness, which is related to how willing one is to risk possible public humiliation, can be eliminated as an obstacle when opportunities for anonymous participation are offered, as is possible with CRSs. Clifford reported that reluctant risk-takers were interested in ‘academic risk-taking tasks’ and could be encouraged to engage in them. In addition, these tasks improved learning outcomes and led to students trying harder (Clifford, 1991).

The issue of autonomy and self-determination plays a major role in connection with intrinsic motivation (Deci & Ryan, 1990; Deci, Vallerand, Pelletier, & Ryan, 1991). McKeachie refers to Deci and Ryan's work when he states that

> ... human beings have a fundamental need for autonomy and self-determination (Deci & Ryan, 1985). Most individuals want to be in charge of their own behavior and value a sense of control over their environment. We can enhance students' sense of control by offering choices and supporting their autonomy, which in turn enhances motivation. (2002, p. 119)

Not only is a learning environment that fosters intrinsically motivated learning behavior desirable, it is also important to take into consideration what past experiences learners bring to the new learning task. Much educational research is dedicated to pre-instructional conceptions and a flurry of terminology describes them. The most frequently used are: misconceptions, preconceptions, alternative conceptions, naïve conceptions, and phenomenological primitives or p-prims (e.g., diSessa, 1993; diSessa & Sherin, 1998; Elby, 2000; Elby & Hammer, 2001; Minstrell, n.d.; Morrison & Lederman, 2003; Posner, Strike, Hewson, & Gertzog, 1982; Redish, 1994; Smith, diSessa, & Roschelle, 1993/1994; Southerland, Abrams, Cummins, & Anzelmo, 2001; Wandersee, Mintzes, & Novak, 1994). These different terms point to varied understandings of their function. The term misconception indicates that an idea is entirely out-of-place, that it must be eradicated and replaced with a more correct conception. However, some alternative conceptions, such as Aristotelian ideas of the physical world, are based on observations that can be made every day. The understanding of motion without the effects of air resistance or friction as developed in Galilean or Newtonian frameworks requires the learner to clarify when, where, and why these are different from what s/he observes in everyday settings. It is, in Piagetian terms, accommodation that is necessary, a sort of contrasting, adapting, and fine-tuning of a schema. This idea of building on and refining an earlier understanding much better describes the initial way of thinking about the concept as an alternative conception. Models that scaffold learning emphasize the necessity of understanding learners' initial and changing ways of thinking about a process. For example, Jim Minstrell's work centers on this idea of eliciting prior schemata and refining the instances of their applicability (van Zee & Minstrell, 1997). Minstrell's group uses a diagnostic tool, the Diagnoser, to identify how students think about a given concept. Diagnoser questions are paired and matched on the reasoning students may apply for a particular facet choice. In their use they found that students "are surprisingly consistent between their predictions and their reasoning…do not necessarily use the same facet of thinking in questions that have different contexts ... likely hold more than one facet of thinking at a given time" (Kraus & Minstrell, 2002).

The social aspect of constructivism is equally important as all learning occurs in a larger community, cast against a wide variety of inter- and intrapersonal criteria and events. Research has shown that impressive learning gains occur during peer interactions (Mazur, 1997; Tudge & Rogoff, 1989; van Zee & Minstrell, 1997). Here, negotiations take place between individual learners, each with an individualistic idea of a particular concept. Part of the benefit is temporal in nature; specifically, it is affected by the amount of time that has passed since one has figured out how something works. Since a successful struggle with new ideas is most likely to be more recent for a peer than it is for the instructor, the peer is more likely to remember what obstacles s/he experienced.

Two models of interactive physics education will be discussed in some detail here: Mazur's "Peer Instruction" (PI), and the Classtalk question cycle developed by Dufresne et al.

Eric Mazur's classroom sessions used to be traditional in nature until he realized that his students did, as a rule, not gain the conceptual understanding he thought they left his classroom with. He developed a system of brief lectures followed by question-and-answer sessions, so-called "ConcepTests", to help students focus on the essential components of a concept, to make use of powerful peer-peer interactions, as well as to get and provide feedback and formative assessment segments. Since ConcepTests take up some of the class time, students are required to read ahead and to come to class prepared. Each class meeting begins with brief 'special' ConcepTests about the readings that allow the students to earn bonus points, a practice that aligns with the earlier described JiTT philosophy. The details of this system are described in his book "Peer Instruction" (Mazur, 1997a).

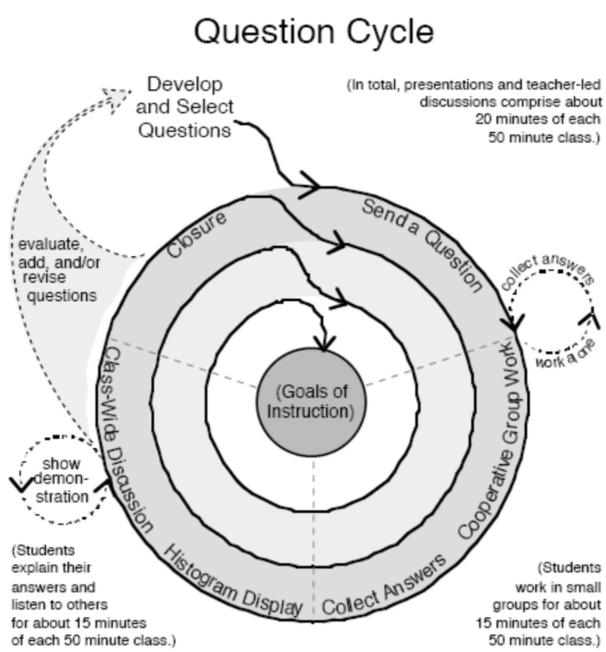
In non-CRS classrooms, Mazur asked students to respond by holding up signs with the answer option of their choice (p. 17). However, getting an accurate count of the distribution of these choices was difficult in a large lecture class. CRSs support this function through reliable aggregation of inputs and immediate, easily interpretable output in the form of a histogram. Yet, the author points out “that the success of Peer Instruction is independent of feedback method and therefore independent of financial or technological resources” (p. 18).

Part of the method rests on the learning environment that is created by the instructor. Eric Mazur explains the use of this method to students at the beginning of the course, and emphasizes that in-class interactions are cooperative rather than competitive in nature. Other than the ‘special’ ConcepTests for bonus points, the results of ConcepTests are used only formatively and with the option of anonymous participation to reduce anxiety. Mazur reports that Peer Instruction positively impacts student performance on conceptual test items, is at least as successful as traditional pedagogies in regards to quantitative test items, and improves student satisfaction with the course.

Dufresne et al. developed their own CRS supported instructional cycle. The description that follows is heavily based on their 1996 paper “Classtalk: A Classroom Communication System for Active Learning”. The authors state that they developed a pedagogical use of the CRS based on “…a) research on misconceptions, b) research on the knowledge structures of experts and novices, and c) research on the effects of motivation and classroom contextual factors on learning" (p. 5).

Much like Mazur's Peer Instruction, the group relies on peer interactions in small group settings, as well as whole-class evaluations. Conceptual discussions follow a cyclical path where one question tends to naturally lead to an exploration of a related question. Although the most frequent sequence consists of specific stages, it is not rigid in nature. Rather, the classroom discussion itself determines the specific pathway for a particular question and so the cycle shown below is a generalization only and the authors indicate points of deviation from the cycle with dashed lines (see Figure 2.2 below). The particular steps are: "1) question generation and selection, 2) sending the question, 3) cooperative group work, 4) collection of answers, 5) histogram display, 6) class-wide discussion, and 7) closure." (p. 9)

Figure 2.2: Generalized Structure of a Classtalk Questioning Cycle. (Dufresne et al., 1996)



While instructors come to class with certain pre-planned questions, it is ultimately the class as a whole that determines which questions get asked and discussed. The authors estimate that student discussions account for about two-thirds of a typical class period.

The researchers varied response modalities in the course of the semester by sometimes requiring students to respond individually only and other times as a group but with dissent option. Although their student interviews indicated that there was a difference in how committed students were to the choices they selected (more committed in the individual response), they did not indicate that there are any differences in either the quality of the discussions or in the learning outcomes themselves (p. 17). This aspect deserves more attention, because not all researchers consider requiring individual responses as equally important. For example, Eric Mazur's Peer Instruction uses the initial individual response as an element that creates a need to think about the question, and which becomes a subsequent artifact of importance. Since group discussion follows after the student has already considered the meaning of the question and its solution, each group member has a specific starting point.

Thus, literature on cognition emphasizes the importance of eliciting prior conceptions. The completely anonymous and group-based use of the CRS provides opportunities for students to examine their thinking but does not necessarily elicit the thinking of each student. Therefore, this literature does not make a clear prediction of whether the treatment condition will be more beneficial for learning than a show of hands. However, the literature does support the idea that completely anonymous use of the CRS may promote agency and the emphasis on understanding permitting by the CRS may foster an orientation toward mastery as opposed to procedural goals.

Summary

Present in the CRS literature are considerations of the general learning literature, specifically constructs of learning models. There is great agreement that CRSs promote learning when coupled with appropriate pedagogical methodologies. While the focus is on engaging and interactive practices, the specifics of CRS use are only well defined for individual student response modalities and for conditions where instructors can trace who responded how to a given question. At the same time, instructors report that overhead needs connected to individual use are cumbersome and may lead to abandonment of the technology.

The literature also indicates that CRS-supported environments lead to greater learning gains than traditional learning environments. However, since the comparison is between traditional and interactive engagement models, it is impossible to assess the effectiveness of the technology itself. Further, almost all of the reports in the literature are based on use in individual mode. There also is no research on CRS impacts on learning and attitudes in primarily female, and primarily Hispanic and White classrooms.

Reported research relies heavily on surveys and test results, some based on one single instrument, others using combinations of instrumentation, but few integrating data from more than two sources. As Penuel et al. (2004) note, it is necessary to expand current research models to gain a better understanding of the technology's affordances and limitations.

To add to the existing body of literature, this study addresses these as of yet unexplored aspects of CRS-related research by comparing two otherwise identical learning environments with a focus on entirely formative assessment of completely anonymous group-based responses. The population consists primarily of female Hispanic and female White students enrolled in a pre-service teaching program. In addition, a diverse set of quantitative and qualitative instrumentation attempts to offer a more contextualized analysis of findings.

CHAPTER 3

METHOD

Introduction

Identifying best practices for use of CRS is especially important considering that they are being more-and-more widely used. Although some researchers are working on defining pedagogies that optimize the use of this technology, many questions remain open (see Chapter 1). In this study, the focus is on identifying the benefits and limitations of using electronic response systems in one particular set of conditions: in formative assessment events based on small group decisions, with fully anonymous response collection, and with a derivative of JiTT pedagogy. Fully anonymous response collection, as defined here, means that neither the classroom population at large, nor the instructor, know what response a particular student chose, or whether an individual even gave a response, as transmitters were given to small groups rather than individuals.

The study follows a mixed model methodology for several reasons: A purely quantitative study provides data that are generalizable; however, it does not provide insights into patterns of thinking and understanding. Rather, it is a measure based on specific questions that is somewhat decontexualized. On the other hand, a purely qualitative study may be exceedingly subjective in nature. By combining the two methodologies into a mixed model, it is possible to incorporate the advantages of both while at the same time mitigating the disadvantages of each. A recent article specifically focused on the pragmatism of such a holistic approach (Johnson & Onwuegbuzie, 2004). The authors argue that quantitative models tend to focus on theory or hypothesis testing rather than hypothesis generation, causing a confirmation bias. On the other hand, qualitative studies may lead to findings that are more difficult to generalize and that may be influenced by personal biases.

Participants in this research project were enrolled in an interdisciplinary studies course at UTSA, and, for the most part, plan to teach in EC-4 or 4-8 classrooms as generalists. The study took place with two sections of IDS 3203, Physical Science, during the spring semester of 2005. The particular CRS in use was the Personal Response System (PRS; US Patent 6,289,222; EduCue, Alplaus, NY), which was obtained through a technology mini-grant. Students in both sections were asked to respond to some of the same question prompts; however, at different times and on different topics. During the period of study for each topic, only one section responded anonymously with the CRS, while the other responded by show of hands and thus in a very public manner.

A variety of data were collected: Students completed a pre- and posttest on two topics in physics education: Newtonian mechanics and thermodynamics. In addition, students completed an on-line general science attitude survey (VASS – Views about Science Survey) and an on-line survey regarding the use of a CRS in their particular classrooms. To gain better insight into the dynamics of their particular learning processes, students were asked to write open-ended reflections on their thinking and learning in mid-semester, as well as to respond to some general prompts on a weekly basis. In addition, students were audio- and video-recorded during several classroom interactions. Preliminary data on small group interactions had been collected prior to the main study.

Preliminary and Pilot Studies

A preliminary and a pilot study were executed in the spring and fall semesters of 2004. Both are described below.

Preliminary Study

This study is described in Chapter 2, Section “The C^3 Framework”. The framework that emerged from the data collected in this study focused on the instructor component of CRS classroom interaction. Data analysis indicated that traditional CRSs are too flexible to bring about pedagogical change, but rather make it easier for the instructor to do whatever s/he wanted to do anyway.

Pilot Study

A pilot study in the fall of 2004 served to test instrumentation and process. The study also followed the mixed model described above. Participants were enrolled in either one of two on-campus sections of IDS 3203, Physical Science, at UTSA, both of which met in the same classroom. Section 001 had an enrollment of 70 students and met on MWF 12:00-12:50 pm; section 002 had an enrollment of 71 students and also met on MWF, but from 1:00-1:50 pm. The CRS was used for

Newtonian mechanics discussions in section 001, and for thermodynamics discussions in section 002.

The pre- and posttest component consisted of eight questions, four addressing issues in Newtonian mechanics, and four addressing issues in thermodynamics. In both cases, these questions were embedded in a larger test. While all of the Newtonian mechanics questions were selected from pre-existing instruments, all four thermodynamics questions were developed for this study. Five of these pilot study questions are identical to questions in the pre- and posttest set for the main study. Both sections completed the same pretest on 13 September 2004, before either topic was addressed. All of the pretest questions were then embedded in an examination that students of both sections completed on 27 October 2004. Section 001 students outperformed section 002 students on both topics, regardless of whether the CRS was used for concept discussions or not.

The VASS was administered at the end of the semester. As such it served only as a ‘snapshot’ of student attitudes after concepts had been discussed. According to the rating developed by Halloun and Hestenes (1996), students ranked in the folk and near-folk range of the dimension. That is, their beliefs were like those of novices rather than those of experts in the field.

The results of the Response System Survey indicated that students value the CRS as it helps them to gauge where their own understanding falls relative to their peers; sometimes use the aggregated feedback from a first voting round to guide their selection for the second voting round; and sometimes respond with what they think the instructor wants to hear in spite of different common sense beliefs.

Several small group sessions were held that mimicked the in-class discussion format. All participants volunteered and, since all members of five of these small groups had given informed consent, five group sessions were videotaped. Each group received the same set of optional questions to choose from and selected two mechanics questions and one question from the thermodynamics set. As was usually the case in class, students responded to the questions twice, with feedback between rounds one and two. Regardless of which answer option students chose, the feedback to the first question included information that indicated their choice was a majority selection in a different setting; the feedback to the second question included information that indicated their choice was a minority selection in a different setting. None of the groups used this information to guide their second round of voting to the same question.

As stated above, students also submitted Response System Reflections. These reflections were entirely open-ended. Students were asked to reflect on the use of response systems in any way they wanted to. However, some of the comments seemed guided by items on the Response System Survey. In general, students liked using the response system. Some of the students indicated that they did in fact sometimes selected whatever choice was the majority vote in the first round on a given question; a result that is at odds with statements students made in the small group sessions. Interestingly, quite a few students were unhappy with not having received traditional ‘final answer’ instruction in the course. Some of the feedback specific to individual preferences indicates that some students thought the system was used too much, while others thought it was not used enough; some would have preferred individual use rather than small group use. Even though students were left to choose whether they wanted to stay in the same small group or not, apparently not all were aware of having that choice. Some students wrote that they would have preferred if group memberships had rotated, while others would have preferred if it had stayed static.

Based on the findings of the pilot study, some changes were made in terms of instrumentation. These are reported in the section below (see Instrumentation and Data Collection).

The Study

Participants

Participants in the study were enrolled in either one of two on-campus sections of IDS 3203, Physical Science, at UTSA. As such, the study was executed with a convenience sample. Initial enrollment in both sections was equal with 103 students. The student population was overwhelmingly female (90.3%), overwhelmingly Hispanic or White, and all but three of the students were part of the pre-service teacher program. Since both sections met in the same room, MWF 12:00 – 12:50 pm (Section 001) or MWF 13:00 – 13:50 pm (Section 002), and since the two sections are not significantly different from each other as determined by an independent samples t-test (see Table 4.1), participants can be viewed as coming from the same population. A total of 161 students signed an informed consent form to participate in the study. Of those, a total of 122 students provided information regarding their ethnicity: The majority of 64 are Hispanic, 49 are White, 6 identified themselves as ‘other,’ and the remaining 3 are African-American.

At the end of the study, the pre- and posttest data of 136 students were complete: 58 students from section 001, and 78 students from section 002.

Classroom Procedures

Ground rules were established at the beginning of the semester. Students exchanged ideas with neighbors beginning on the first day of class, and worked both in small groups and as a whole class. It was up to the students whether they wanted to remain in the same small groups throughout the semester or not.

All transmitters were owned by UTSA and were brought to the classroom by the instructor. Since each group randomly picked one of the transmitters at the beginning of a given class period, the likelihood that the same group ended up with the same transmitter in different class sessions was extremely low.

The course is supported with a WebCT course management site. Students have access to all PowerPoint slides used in class, as well as links to supporting applets and tutorials. To reduce the time students spent on note taking, they were encouraged to print the PowerPoint slides before class and to add their own notes to the text already written.

After an initial introduction of a conceptual topic, the instructor presented a question for small group discussion. Once students indicated that they were ready to vote, their responses were collected and the aggregated histogram shown. In cases where the vast majority chose the correct option, discussion moved on. However, usually this was not the case. Rather than telling students immediately which of the answer options was the correct one in those instances, a whole-class discussion followed in which the different options were evaluated in terms of their respective merits and problems. The instructor listed some possibly pertinent conditions, only some of which were applicable; others were introduced as additional distractors. After a second round of small group discussion, student groups voted again on the same question. As before, the aggregation histogram was followed by whole class discussion and closure. This was not a strict protocol; rather, the class was conducted in a JiTT manner. That is, specific sequences and components depended on where students took the discussion and on voting outcomes. What follows is an example of a classroom session.

In preparing for the class meeting on February 9, 2005, students were expected to complete an assigned reading about inertia, speed, velocity and acceleration. In both sections, the instructor first provided a brief overview of the topic. This introduction consisted of a mixture of mini-lecture, question-and-answer segments that situated the terminology in everyday contexts (i.e., driving a car), and demonstrations. This warm-up segment was supported by summary slides that were also available to students online.

The first CRS question in this session asked students to consider a scenario where they are “walking around a block at a steady 2 mph” in terms of velocity. Students discussed the question in small groups and, in the CRS section, voted with their transmitters; in the non-CRS section voted by show of hands. In both sections, the vast majority of students correctly identified velocity as changing under these conditions. Students were then asked to reconsider the same scenario, but this time in terms of speed. In both sections, results indicated that there was a good understanding of what speed measures, and how it is different from velocity. However, in the CRS section, the instructor could be more confident in the distribution of choices in the classroom as the histogram presented the aggregated outcome. The second CRS question of that day asked students to evaluate acceleration when driving “on a flat and straight stretch of road” at a constant speed of 70 mph. This question was asked twice in both sections, as the initial round of voting in both cases indicated a lack of understanding. Between the two voting events, the instructor asked students to explain what made one or another of the answer options a reasonable choice or what excluded it as a reasonable option. Students used arguments based on their everyday experiences, as well as arguments based on their readings. Before the second vote was taken on the acceleration question, the instructor did not directly identify any of the options as valid or invalid. After the second vote, the instructor identified the correct response option and summarized the pertinent arguments. The class ended with the instructor asking students to think about velocity and acceleration in a vertical rather than horizontal context for the next class period.

Instrumentation and Data Collection

IRB approval was obtained at both UT and UTSA. Based on the results of the pilot study, some of the instrumentation remained unchanged from the pilot study, while other components were updated or replaced. All instruments are available in Appendix B.

Pre- and posttest questions were in part retained and in part replaced to accommodate paired questions for each topic. Of the original set of eight questions only five remained in the study set, the other three were substituted. As in the pilot study, four questions focused on mechanics: now two of them addressed force pairs, the other two addressed free fall conditions. Another four questions focused on thermodynamics: two addressed heat flow, the other two temperature and internal kinetic energy (IKE). All eight questions were embedded in a larger 20-question test at the beginning of the semester (pretest), and then again in a 20-question examination around the middle of the semester (posttest).

Both of the force pair questions, and one of the free fall questions were selected from the FCI. The second free fall question was developed by the Mazur Group as one of their ConcepTest questions. All of these have been widely tested and are considered to be good indicators of conceptual understanding. For the four thermodynamics questions, two were adapted from a question set developed by the University of Washington (L. DeWater, personal communication, 2004). One of these applied to the heat flow component, the other to the temperature/IKE concept, both were ‘free-response format’ items in the original document. The remaining two questions were developed by the researcher.

The VASS was administered twice, once at the beginning of the semester and a second time at mid-semester to test whether attitudes changed over that instructional period. The tool was not revised after the pilot study. Both the instrument and its evaluation dimensions are included in Appendix B.

Four questions were added to the Response System Survey to collect data on student perceptions of their understanding, their interest and participation, and their feeling valued and important in discussions. In addition, this survey was administered after Metareflections had been collected instead of before. Audio- and video-recording of small group sessions was dropped from the protocol as they were too removed from the classroom interaction. Student volunteers may have consciously or subconsciously tried to please the researcher by providing only favorable input. Instead, whole-class interactions were video- and audio taped to capture discussions *in situ*.

As in the pilot study, the two sections served as controls for each other: they both participated in the same pre- and posttests, but received the treatment, the use of a CRS, for different topics. Each section also served as a control for itself in that two topics are studied, but the treatment was only administered for one in a given section (Table 3.1).

Table 3.1: Pre- and Posttest Design

Concept	Section 001	Section 002
Mechanics 1. Force Pairs 2. Free Fall	CRS Group	Non-CRS Group
Thermodynamics 1. Heat Flow 2. Temperature/IKE	Non-CRS Group	CRS Group

As mentioned above, students completed two different surveys: the VASS and a CRS survey. The developers of the VASS (Halloun, 1996; Halloun & Hestenes, 1996; 1998) tested the validity of the instrument through several trials with experts and novices. The VASS's reliability was measured with Cronbach Alpha, and ranges "between .78 and .84 depending on the course level and country in which it is administered." (Halloun, personal communication, 2005)

The instrument was used in an identical format to that in the pilot study. However, rather than administering it only once, it was administered twice: once at the beginning of the course, and a second time around the middle of the semester, after the posttest. Results were analyzed regarding where students fall in the authors' schema of profiles: expert, high transitional, low transitional, and folk. In addition, the second collection of VASS data was compared to the first to investigate whether changes in attitudes occurred in the course of the semester.

The CRS survey was expanded from the version administered in the prior year. Four additional questions asked participants to rate their understanding, participation, and interest in the course, as well as whether they felt their input to discussions was important and valued. This survey was administered only once, roughly in the middle of the semester. Results were analyzed regarding student attitudes toward the system and its use.

Whole class discussions of the two concept areas selected for the study were video recorded and analyzed. Before turning on the camera, the researcher reminded students which part of the classroom was in the view finder. They then were given an opportunity to move to an area of the room that was not in the view finder of the camera. All video recordings were first converted to QuickTime™, and then analyzed with the help of FileMaker™ Version 6.0, and the Video Transcriber tool. The Video Transcriber was developed at UT to facilitate qualitative research involving video records (Stroup et al., 2004). Specifically, coding and marking the QuickTime video while developing and integrating it with the FileMaker database aids the researcher by allowing a more fluid manner of analysis. The software thus bridges the two commercial software packages and is available free of cost for academic use. It can be downloaded at http://128.83.243.140/videotranscriber/vtlatest.sit. These files were coded, time-stamped, and peer reviewed to determine whether there was a difference between sections in terms of the JiTT protocol, as well as to determine whether CRS-supported discussions were qualitatively alike or different from discussions not supported by the technology.

Students were asked to write two kinds of reflections. A weekly mini-reflection consisted of two open response prompts and of four Likert-type items that are also contained as the four newly added items in the CRS survey. These two prompts were analyzed in accordance with Grounded Theory (Strauss & Corbin, 1998) and themes were identified within participant comments over time, as well as across participants, but within sections. The initial reading of comments was an intentionally open-minded evaluation of what a given statement means. That is, it was a literal reading as well as an interpretative one. Each student comment was aligned with one overarching category. Where students provided statements that addressed more than a single issue, a decision was made which one of the issues addressed was the most critical one. For example, a student wrote "I missed one class due to a doctor's appointment and others I gave an educated guess to answers raising my hand. However calling out the answer is beyond me because my lack of confidence in my ability to answer correctly." This statement had two components in it: 'Missed class, work' and 'Responds to whole-class prompts only.' Of the two, priority was given to the second as it provided insight into why this student participated in a particular manner. Another student wrote "I have not been much of the type to participate in verbal discussions unless I know the material and what I am talking about. Also, with a larger group, I feel better to sit back, record and absorb the input of others so I may get a better understanding of it. I work better in smaller classes so you can know your people and surroundings better.” Possible categories include ‘Participates only when sure of answer’ and ‘Participates quietly.’ Of those two, the comment was counted for quiet participation as it was the more strongly emphasized.

Open coding resulted in 49 categories, which represent general properties of the collected data. This was followed by axial coding in which eleven dimensions were identified. These represent conditions and content of the classroom interaction. Finally, selective coding integrates the data into an emergent theory. For the specifics of the coding sequence, please see the Results section (Chapter 4). The outcomes of the four Likert-type items were used to compare attitudes across sections, and as a comparison set against the CRS survey.

Aside from these weekly reflections, students submitted one open-ended reflection that was larger in scope. Embedded in the seven prompts for this ‘metareflection’ were two that specifically required thinking about the CRS. The five general background items provide a better understanding of how participants thought of learning and teaching science content and serve to situate comments students provided in response to the CRS prompts. These reflections were coded in accordance with Grounded Theory as above (Strauss & Corbin, 1998).

Methodological Assumptions

A number of basic assumptions guided the design of this study. They are in part based on past experience with the course and student population, and in part on the review of pertinent literature. The assumptions are listed below:

(1) Both sections are comparable in make-up. This seems reasonable: there is only a one-hour difference in class meeting time, and both sections meet in the same classroom.

(2) The student sample is representative of a group of pre-service teachers who plan to work as generalists in elementary and middle schools.

(3) Instruction is consistent across the two sections. Both sections are taught by the same instructor, and with the same resources and materials.

(4) Recorded whole class discussions are representative of all whole class discussions in the classroom.

(5) Survey responses are truthful.

(6) The mixed model is stronger than either quantitative or qualitative research alone.

(7) The following threats to internal validity do not apply: History or maturation, because students in both sections are equally likely to have certain experiences between the pre- and posttest.

Limitations

This study has a number of limitations. First and foremost, participants in the study are pre-service teachers at UTSA who signed up for one of the sections of IDS 3203, Physical Science. As such, the study is based on a convenience sample with non-random assignment, limiting generalizability and threatening external validity.

Each of the subtopics was tested with only two questions. A chance selection of a correct or incorrect response had a disproportionate effect on the outcome, tempering the validity of the finding.

One of the main components of the study, complete anonymity, made it impossible to track in-class CRS response data to individual students. There is no record of how conceptual understanding changed or failed to change on the individual level.

While the instructor is the same for both course sections, there was one identified instance of instructor caused contamination. A question that a student posed in the first section was asked by the instructor in the second section. This was a clear violation of the JiTT protocol.

There also is the possibility of a Hawthorne effect in that participants may act in certain ways only because they are aware of the scope of the study. Students submitted weekly reflections and one metareflection, all of which sensitized them to the types of issues the researcher was interested in.

Further, the fact that survey data are self-reported represents an additional threat to validity, as do both the pretest/posttest design, and experimental mortality. The population is less representative because only data from students who voluntarily signed the IRB form are included in the test results. Of the students who did not sign the IRB form, five are male, all others are female.

Final limitations have to do with coding of the open responses on the reflections. Coding was done only by the researcher and no inter-rater cross checking was performed. There is a possibility that student attitudes were not interpreted correctly due to coding errors.

Summary

This chapter briefly presents findings from the preliminary and pilot studies, and describes the current study. The student population is primarily female, Hispanic or White, and enrolled in UTSA's per-service teacher program. Classroom interactions are heavily based on small group and whole group discussions. The study makes use of several research tools, both quantitative and qualitative. Results are presented in the following chapter, and will be discussed in Chapter 5.

CHAPTER 4

RESULTS

Results of this study are presented in the same order in which the instruments were presented in Chapter 3. That is, first pre- and posttest data, then the two surveys, VASS and CRS. This is followed by results from the whole-class video record analysis, and finally by the two types of reflections: weekly reflections and metareflection.

Pre- and Posttest Findings

Discussion of the pre- and posttest findings will be broken down into the two main topics addressed in this study: Mechanics and Thermodynamics. The hypotheses tested are:

H_0: $\mu \geq \mu_{CRS}$ (Use of a Classroom Response System does not improve learning outcomes in physical science.)

H_1: $\mu < \mu_{CRS}$ (Use of a Classroom Response System does improve learning outcomes in physical science.)

Data are normally distributed, homogeneous, independent and spherical, and as such can be assumed to come from the same population. The results of the independent samples t-test on pretest data are presented below (see Table 4.1). According to Levene's Test, equal variances could be assumed for all but the Force Pairs component. However, none of the subtopics indicated a statistically significant difference between the two sections.

Table 4.1: Independent Samples t-test, Pretest Data

Measure	Equal variances assumed (Levene's Test)	t	df	Significance (2-tailed)	Mean difference	95% Confidence Interval of the difference	
						Lower	Upper
Force Pairs	no	1.477	108.329	.143	.06565	-.02244	.15374
Free Fall	yes	-.309	134	.758	-.01370	-.10134	.07393
Heat Flow	yes	-1.266	134	.208	-.07029	-.18010	.03952
Temperature, IKE	yes	.907	134	.366	.05659	-.06675	.18094

Data presented below include pre- and posttest results for all students who signed the IRB, and who also answered at least half of the questions on each of the two measures (n = 136). Student responses were coded as "1" if they were correct and as "0" if they were incorrect choices. If students left any of the questions unanswered, but did respond to at least half of the questions on the test, then those items were also coded as "0." Thus, a student who responded correctly to both questions in a given subset would receive a rating of "1" for that subset and test, while a student who responded correctly to only one of the two questions in a subset would receive a rating of "0.5" for the measure. All reported means are based on section and measure. Here, a mean of "1" would indicate that all students in either one of the sections had chosen correct responses on both questions of a sub-topic for either the pre- or posttest; a mean of "0.5" would indicate that half of all responses in that section and for that sub-topic were correct. In addition, data tables summarize the results of within-subject contrasts for each sub-concept.

Aside of the reported statistical evaluation of this full data set, a second run was completed selecting only data provided by female students. While means slightly changed, all significance results remained the same.

Mechanics

The four mechanics questions focused on two different sub-concepts: force pairs and free fall conditions. All four questions were selected from pre-existing and widely tested instruments, the FCI and the Mazur group's ConcepTests. Each of the two sub-concepts is presented separately, with the force pair set being listed first. The two questions addressing this concept consisted of a horizontal collision scenario and a vertical tension condition (see Appendix B). Table 4.2 below shows results for the Force Pair means by section and measure.

Table 4.2: Mechanics Questions, Force Pair Means

Section	n	Measure	Mean	Standard Error	95% Confidence Interval	
					Lower Bound	Upper Bound
001, CRS Group	58	Pretest	.181	.033	.116	.246
		Posttest	.293	.039	.216	.370
002, Non-CRS Group	78	Pretest	.115	.028	.060	.171
		Posttest	.295	.034	.229	.361

Although both groups showed statistically significant gains in learning outcomes ($_{.95}F_{1,\,133} = 23.669$, $p < .001$; power: 0.998), there is no statistically significant difference between the two sections. Thus, use of the CRS itself did not improve learning outcomes. Table 4.3 below presents the outcome of the Tests of Within-Subjects Contrasts for the Force Pair component.

Table 4.3: Mechanics Questions, Force Pairs, Tests of Within-Subjects Contrasts

Source	df	Mean Square	F	Significance	Observed Power
Mechanics Instruction	1	1.414	23.669	.000	.998
Mechanics Instruction*Section	1	.076	1.266	.263	.201
Error	134				

The second set of the mechanics questions centered on free fall conditions. Of those, the first question asked students to compare the acceleration of a falling object that was released with a velocity of 0 m/s to one that was released with a velocity greater than 0 m/s. The second question involved assessment of forces on an object that is initially thrown upwards and then falls to the ground (see Appendix B). Table 4.4 below shows results for the Free Fall means by section and measure.

Table 4.4: Mechanics Questions, Free Fall Means

Section	n	Measure	Mean	Standard Error	95% Confidence Interval	
					Lower Bound	Upper Bound
001, CRS Group	58	Pretest	.147	.034	.080	.213
		Posttest	.147	.030	.087	.206
002, Non-CRS Group	78	Pretest	.160	.029	.103	.217
		Posttest	.141	.026	.090	.192

Regardless of whether the CRS was used or not, neither group improved scores on the posttest (${}_{.95}F_{1,\,133} = .130$, $p = .719$; power: .065). In fact, there is no difference in pre- and posttest means for the CRS group, and a slight drop for the non-CRS group. There also is no statistically significant difference between the sections. Table 4.5 below presents the outcome of the Tests of Within-Subjects Contrasts for the Free Fall component.

Table 4.5: Mechanics Questions, Free Fall, Tests of Within-Subjects Contrasts

Source	df	Mean Square	F	Significance	Observed Power
Mechanics Instruction	1	.006	.130	.719	.065
Mechanics Instruction*Section	1	.006	.130	.719	.065
Error	134	.047			

Thermodynamics

As was the case for the mechanics component, the four thermodynamics questions focused on two different sub-concepts: the first is heat flow, and the second centers on temperature and internal kinetic energy (IKE) conditions. One question for each of these two components was adapted from instruments developed by the University of Washington (see Chapter 3). The remaining two questions were developed for this study and are based on difficulties students experienced in prior semesters.

Again, each of the two sub-concepts is presented separately. The first set addresses results for heat flow questions. The two items of this sub-concept consisted of a cooling scenario and a warming condition. (see Appendix B). Table 4.6 below shows results for Heat Flow means by section and measure.

Table 4.6: Thermodynamics Questions, Heat Flow Means

Section	n	Measure	Mean	Standard Error	95% Confidence Interval	
					Lower Bound	Upper Bound
001, Non-CRS Group	58	Pretest	.276	.042	.193	.359
		Posttest	.414	.047	.322	.506
002, CRS Group	78	Pretest	.346	.036	.274	.418
		Posttest	.506	.040	.427	.586

Posttest results indicate a statistically significant gain in learning outcomes ($_{.95}F_{1,\,133}$ = 17.899, $p < .001$; power: 0.987). However, there is no statistically significant difference between the sections, indicating that the use of the CRS alone does not lead to statistically significant change. Table 4.7 below presents the outcome of the Tests of Within-Subjects Contrasts for the Heat Flow component.

Table 4.7: Thermodynamics Questions, Heat Flow, Tests of Within-Subjects Contrasts

Source	df	Mean Square	F	Significance	Observed Power
Thermodynamics Instruction	1	1.479	17.899	.000	.987
Thermodynamics Instruction*Section	1	.008	.100	.752	.061
Error	134	.083			

The second set of the thermodynamics questions centered on temperature and IKE. Of those, the first question asked students to compare energy conditions between two temperatures given in degrees Fahrenheit. The second question required students to compare final temperatures of two different volumes, given that both volumes receive an identical amount of heat flow (see Appendix B). Table 4.8 below shows results for Temperature and IKE means by section and measure.

Table 4.8: Thermodynamics Questions, Temperature and IKE Means

Section	n	Measure	Mean	Standard Error	95% Confidence Interval	
					Lower Bound	Upper Bound
001, Non-CRS Group	58	Pretest	.371	.047	.277	.464
		Posttest	.534	.043	.449	.620
002, CRS Group	78	Pretest	.314	.041	.234	.395
		Posttest	.615	.037	.542	.689

Regardless of whether the CRS was used or not, both groups received higher scores on the posttest than on the pretest. The gain is statistically significant ($_{.95}F_{1, 133} = 33.991$, $p < .001$; power: 1.000). Again, there is no statistically significant difference between the sections, indicating that CRS use itself does not lead to significantly higher learning outcomes. Table 4.9 below presents the outcome of the Tests of Within-Subjects Contrasts for the Temperature and IKE component.

Table 4.9: Thermodynamics Questions, Temperature and IKE, Tests of Within-Subjects Contrasts

Source	df	Mean Square	F	Significance	Observed Power
Thermodynamics Instruction	1	3.597	33.991	.000	1.000
Thermodynamics Instruction*Section	1	.314	2.971	.087	.402
Error	134				

Summary of Pre- and Posttest Findings

None of the pre- and posttest findings indicate that use of a CRS leads to statistically significant learning gains when all other conditions of classroom interactions are held constant. Where learning gains occurred, they did so in both sections.

Survey Findings

The two surveys administered consisted of the Views About Science Survey (VASS) and a CRS survey. The VASS was completed once in the fall semester 2004, and twice in the spring semester 2005. The CRS was administered in the spring and fall of 2004, as well as in the spring of 2005.

Views About Science Survey

The VASS investigates student attitudes towards science, and as such serves as general background information on student attitudes. Results comparing student attitudes across the fall 2004 and spring 2005 semesters indicate that the two groups were homogeneous and that there were no statistically significant differences between student populations of the two semesters in terms of the VASS dimensions and criteria. As such, the population of the current study can be considered to be typical of students taking IDS 3203, Physical Science, at UTSA. This comparison includes only data collected at the respective midpoints of the two semesters. Group statistics are listed in Table 4.10 below.

Table 4.10: Group Statistics for VASS, Fall 2004 and Spring 2005 Data

Dimension, Criterion	Semester	N	Mean	Std. Deviation	Std. Error Mean
Scientific, Structure	F 2004	117	1.2085	.20909	.01933
	Sp 2005	116	1.2418	.20515	.01905
Scientific, Methodology	F 2004	117	2.7953	.47489	.04390
	Sp 2005	116	2.7375	.45243	.04201
Scientific, Validity	F 2004	117	2.5848	.52536	.04857
	Sp 2005	116	2.6578	.50241	.04665
Cognitive, Learnability	F 2004	117	2.4679	.50806	.04697
	Sp 2005	116	2.4662	.50421	.04681
Cognitive, Reflective	F 2004	117	2.5858	.66068	.06108
	Sp 2005	116	2.7447	.57652	.05353
Cognitive, Personal Relevance	F 2004	117	3.0178	.67840	.06272
	Sp 2005	116	3.1078	.66857	.06207

During the spring semester of 2005, the VASS was administered twice: the first time at the very beginning of the semester, the second time at roughly the midpoint, after the posttest. A paired samples t-Test was performed to investigate whether there were any changes in attitude. The only statistical significant difference that exists in this comparison is for the learnability criterion in the cognitive dimension. Students scored this dimension lower in the second round of data gathering than at the beginning of the semester ($_{.95}t_{115} = -2.056$, $p = 0.042$). See Table 4.11 below for details. The authors of this instrument describe the learnability criterion as probing whether students interpret science learning as possible for everyone; whether they believe it is dependent on personal effort or requires special talents, and whether they think it is dependent on the quality of the teacher and textbook.

Table 4.11: Paired Samples t-Test on VASS Data, Spring 2005

Dimension, Criterion	Paired Differences					t	df	Significance (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Scientific, Structure	.00560	.29220	.02713	-.04814	.05934	.207	115	.837
Scientific, Methodology	-.04569	.61026	.05666	-.15792	.06655	-.806	115	.422
Scientific, Validity	.05948	.66705	.06193	-.06320	.18216	.960	115	.339
Cognitive, Learnability	-.12931	.67739	.06289	-.25389	-.00473	-2.056	115	.042
Cognitive, Reflective	.00096	.79559	.07387	-.14536	.14728	.013	115	.990
Cognitive, Personal Relevance	.03089	.85667	.07954	-.12666	.18844	.388	115	.698

CRS Survey

This survey was developed to collect student attitude data specifically regarding CRS use. It was administered in the spring and fall semesters of 2004, as well as in the spring semester of 2005 after adding another question (see Chapter 3). With the exception of question 4, which required a 'yes/no' type of response, students evaluated each statement on a 5-point Likert scale. The selection of 'strongly disagree' was converted to a score of 1, the selection of 'strongly agree' was converted to a score of 5. In the case of questions 1, option d, and question 3, data were recoded to keep numerical comparisons more consistent in terms of where the less and more desirable outcomes lie along the number line. In the case of question 1, option d, the statement itself is negative in nature as one would hope that students are not losing their confidence in the course of instruction. Here, the coding scale was reversed so that the more desirable outcome, namely 'strongly disagree,' ranked at the high end of the scale. Results are presented only for the Spring 2005 semester (see Tables 4.12 – 4.16).

Question 1: How did the feedback through the histogram influence your study behavior in this class?

Table 4.12: Descriptive Data for CRS Question 1

Rated Statement	N	Mean	Median	Mode	Std. Deviation
Helped me to focus on topics where I needed more study time.	114	3.43	4	4	.841
Made me aware of where my understanding falls compared to the class	114	3.98	4	4	.931
Built up my confidence level	113	3.53	4	4	.964
Lost my confidence. (Note: Recoded)	113	4.25	4	5	.808

Question 2: If you purchased the transmitter, which of the following did you consider being most beneficial?

The results of this question were removed for the following reasons: First, none of the students in the researcher's courses purchased the transmitter; Secondly, scores for the four rated statements range between 3.19 and 3.41 and as such are fairly neutral. Please see Chapter 5 for further discussion.

Question 3: If you were given a second opportunity to make a selection, did you tend to select whichever option was the most frequently selected in the first round? (Note: Recoded Data)

Table 4.13: Descriptive Data for CRS Question 3, recoded

N	Mean	Median	Mode	Std. Deviation
112	3.42	4	4	1.128

Question 4: Did you at any time during the semester make a selection because you thought it was the response your instructor wanted to hear, even if your common sense told you that another option was the correct one? (Note: Options were limited to either "Yes" – coded as 1 – or "No" – coded as 2.)

Table 4.14: Descriptive Data for CRS Question 4

N	Mean	Median	Mode	Std. Deviation
113	1.80	2	2	.403

Question 5: IF YOU ANSWERED "YES" TO QUESTION 4, please also answer the following question: Rate the following as possible reasons why you might have made a choice against your 'common sense:'

Table 4.15: Descriptive Data for CRS Question 5

Rated Statement	N	Mean	Median	Mode	Std. Deviation
I am never right in this class, so I pick what I think is the least likely correct answer.	23	2.30	2	2	.822
I've only done that when the concept was very counter-intuitive.	23	3.17	3	4	.887
I cannot think about these things in everyday ways, so I put myself in 'class-mode' and try to answer the questions based on what I read and heard in class only.	23	3.74	4	4	1.054
I have a pretty good understanding of when my common sense works or does not work in this class.	23	3.48	4	4	.730

Question 6: Please indicate the degree to which you agree or disagree with the following statements.

Table 4.16: Descriptive Data for CRS Question 6

Rated Statement	N	Mean	Median	Mode	Std. Deviation
I understand the ideas presented in the course.	98	3.42	4	4	.930
My input to in-class discussions was important and valued.	98	3.68	4	4	.768
I participated in every class session.	98	3.42	4	4	1.004
I was interested in the ideas presented in this course.	98	3.64	4	4	.840

Whole Class Video Records

These video records were evaluated in terms of to what degree the instructor's practice is in fact aligned with JiTT. That is, whether student responses influence the direction of the whole class discussion. In addition to analysis by the researcher, all records were evaluated by Dr. Jill Marshall as peer reviewer. The two independent evaluations resulted in greater than 90% coding agreement.

Video records were available for both sections on three different class days: February 9, 23, and 28. Section 001 served as the CRS group on 9 February, and Section 002 students used the CRS on the other two days. Discussion in each section was broadly structured by questions the instructor had prepared; however, student responses and questions could take the overall discussion into different directions. One violation of the protocol occurred on 9 February: a student in Section 001, the CRS group at that time, asked whether it did not matter how long one was in a zero-acceleration condition. None of the students in Section 002 asked that question, but the instructor posed it instead. However, the duration of a zero-acceleration condition was not an aspect of any of the pre- and posttest questions.

Overall, the video records indicate that students participate more when responding with CRS than when asked to raise hands. This is evidenced by students being twice as likely to respond to each other during whole class discussions in CRS supported sessions as they are without the technology. Additionally, the percentage of time students are involved in discussions in each case indicates that they are in general more vocal during CRS sessions. Even though the time percentage of section

001 increased over time, possibly due to students becoming more relaxed as they became more familiar with their peers and instructor, it only exceeds section 002 time percentages on the date section 001 was the CRS group (Table 4.17). Problematic is that student groups need different amounts of time to complete their discussion of assigned questions. Without doubt, some of the groups moved on to non-class related conversations while others were still working on the question. Since the instructor did not wish to rush students unduly, she monitored the response count of the system and asked students to indicate whether they needed more time. This practice was followed in both sections.

Table 4.17: Percentage of Time Students Talked Per Class Meeting (Data for CRS sections are indicated in bold lettering)

Date	Section 001	Section 002
Feb 9	**48.5**	28.8
Feb 23	61.3	**89.4**
Feb 28	77.8	**81.3**

An interesting observation is that the more involved discussions during CRS use do not carry over to either voting behavior or discussions in connection with ‘raising hands’ questions at a later point. That is, participation in Section 001, the initial CRS group, was higher during the CRS segments than it was afterwards, when the section became the non-CRS group. On both February 23 and 28, half of the ‘raise your hand’ voting events resulted in the majority of students in the non-CRS section abstaining. Students were also only about half as likely to respond directly to other students’ comments during whole-class discussion.

Reflections

Spring 2005 students submitted two kinds of reflections: one brief weekly reflection that was completed at the end of a given week, and one metareflective writing that was completed around mid-semester. Weekly reflections provide insight into student attitudes in an ongoing fashion; however, as they were completed at the end of each week during class time, often consist of hurried notes. Students had two weeks to think about and to write the metareflective essay, and, in general, offered more explanation.

Weekly Reflections

Weekly reflections consisted of four questions that required 4-point Likert-type ratings (see Table 4.18). In addition, students were asked to respond to two open-ended questions. Results for the first four questions are summarized first.

Table 4.18: Coding Summary of Weekly Reflection Prompts 1-4

Prompt	Code: 1	Code: 2	Code: 3	Code: 4
My understanding of this week's class discussions is	very good	good	weak	none
This week, I felt that my input was	very important	somewhat important	not very important	completely ignored
This week, I felt that I participated	all of the time	most of the time	every now and then	not at all
My interest in class this week was	very high	high	low	none

Student ratings of these first four items are largely consistent over time and across sections. The exception occurred between the two successive weeks in which roles regarding CRS use were switched between the two sections. That is, reflections written on 18 February 2005 were based on Section 001 being the CRS group, and reflections written on 25 February were based on Section 002 being the CRS group. Difference scores were calculated by subtracting each student's rating on 25 February from the rating on 18 February (Table 4.19). Cases where either one was missing for a particular question were excluded.

Table 4.19: Weekly Reflection Prompts 1-4; Means of Difference Scores between 18 and 25 February 2005

Question	Section	N	Mean	Std. Deviation	Std. Error Mean
My understanding of this week's class discussions is	001	49	.1020	.71429	.10204
	002	44	.2273	.71083	.10716
This week, I felt that my input was	001	47	.2553	.82008	.11962
	002	44	.3636	.68509	.10328
This week, I felt that I participated	001	48	.2708	.84399	.12182
	002	45	.6667	.92932	.13853
My interest in class this week was	001	48	.1667	.55862	.08063
	002	45	.1333	.78625	.11721

The statistically significant difference is based on part 3, regarding the students' rating of their own participation ($_{.95}t_{91}$ = -2.152, p = 0.34; Levene's Test for Equality of Variances: F = 1.768, p = .187). That is, students in section 002 who just had begun to use the CRS rated their participation significantly higher in that week compared to the prior week and to the other section (Table 4.20).

Table 4.20: Weekly Reflection Prompts 1-4; Independent Samples t-Test on Difference Scores between 18 and 25 February 2005

Question	T	df	Significance (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
1	-.846	91	.400	-.12523	.14801	-.41924	.16878
2	-.681	89	.497	-.10832	.15898	-.42420	.20757
3	-2.152	91	.034	-.39583	.18390	-.76113	-.03054
4	.237	91	.813	.03333	.14074	-.24624	.31290

The other two weekly items required students to reflect in a free response format regarding their participation and on the possible effects of the CRS on their in-class responses. Results of these two questions are presented individually below.

Prompt 5: "Explain why you responded the way you did regarding your participation."

Student responses ranged from non-interpretable responses (example: "We should go and play red rover, red rover") to two- or three-sentence statements. The 550 comments provided were coded into 26 open codes (see Table 4.21). The rules for why one or another comment was included in one of these categories are listed in the same table.

Table 4.21: Weekly Reflection Prompt 5; Open Code List and Code Rules

Code Number	Open Code	Code Rules
1	Boring	Direct statements indicating that an aspect of the course was 'boring.'
2	Confused	Direct statements indicating that an aspect of the course was 'confusing.'
3	Discussion-related	Any statement that referred to discussions, but that did not state they were either confusing or boring.
4	High School-related	Any statement that referred to the students' High School experience in physical science. Includes comments such as remembering concepts, understanding them, or a comparison of instructional settings.
5	Interest, none	Direct statements indicating that students were 'not interested' in topics of the course.
6	Interested	Direct statements indicating that students were interested in topics of the course.
7	Language concerns	Specific statements regarding ELL issues, such as difficulties with vocabulary or grammar.
8	Mathematics issues	Specific statements indicating that students were concerned with mathematical aspects of the course. Includes statements of general math-anxiety, as well as concerns with a particular algorithm.
9	Missed class, work	Any statement indicating that students missed class sessions, or did not turn in assigned work, due to either personal illness or family issues.
10	Not interpretable comment	Any comment that did not in any way address the course. See example given above (playing red rover, red rover).
11	Not hog class time	Direct statements indicating that students either did not want to 'hog class time' or that they thought others did.
12	Other classes' impact	Specific statements regarding the impact of other courses on the time available to work on this course, such as high workload, testing.
13	Pace, too fast	Direct statements indicating that the students thought the course was progressing too quickly.
14	Pace, too slow	Direct statements indicating that the students thought the course was progressing too slowly.
15	Participates quietly	Specific statements indicating that students were attentive, but did not participate openly. However, without stating 'shyness' or 'being sure' as a reason, and without referring to CRS use or non-use.
16	Participates only when sure of answer	Direct statements indicating that students only openly participated when they were sure of the answer. Includes statements that indicate the student did not prepare for the course and then did not participate because of a lack of understanding.
17	Participates more with CRS	Direct statements indicating that students felt they participated more frequently during sessions in which the CRS was used.
18	Participates less	Statements indicating students felt that they participated less than they could have. However, without stating any reasons.
19	Test-related issues	Specific statements indicating that students were anxious about testing events. Includes statements before and after a testing event.
20	Responds to whole-class	Specific statements indicating that students only responded to whole-class prompts, regardless of whether the CRS was in use or not.

	prompts only	
21	Shy	Specific statements indicating that students chose not to participate openly because they were 'shy' or because they felt intimidated by the size of the class.
22	Sick, but in class	Specific statements indicting that students did not participate much because they felt ill. However, they did attend class.
23	Sit in back, hard to be heard	Specific statements that where students were sitting in the classroom hindered participation. Includes statements regarding sitting in the back of the room, as well as other statements where students expressed a reluctance to speak up due to their location. Does not include statements where students indicated they were 'shy.'
24	Stress-free discussion	Direct statements that discussions were not causing a stressful situation for students.
25	Talk in small groups only	Direct statements indicating that students were comfortable with small group discussions, but not with whole-class discussions. Does not include statements that addressed discussions as being stress-free, or boring, or confusing.
26	Understanding	Specific statements in which students evaluated their understanding of course materials.

Axial coding led to an understanding of participation as driven by issues of personality, of in-class practice and external demands, as well as of expectations based on prior educational experiences. A total of six axial codes resulted: discussion, interest, understanding, non-class related issues, anonymity, and traditional concerns. Of those, non-class related issues were set aside as they did not provide any insights into research questions.

Selective coding that integrates across axial coding resulted in a three-dimensional model, which is presented as the C^3 Framework (Chapter 5).

What follows is a listing of how often students made specific statements. Several trends were consistent across the two sections and across the CRS and non-CRS conditions. These are: (1) Students tended to be reluctant to make public statements if they are unsure of whether they are correct or not; (2) The larger the group, the more reluctant students were to publicly participate; (3) Students were more likely to participate in small group discussions than in whole class discussions; (4) Students were more likely to participate during CRS sessions than during non-CRS sessions; (5) Topics that were of high interest to students also were those where students stated they had a better understanding of the concept and where they rated their participation as high.

Of a total of 550 comments, 291 directly addressed participation. Student notes indicate that there is a diverse understanding of what participation is. Some wrote that their participation is good because they attend class meetings, or because they read the textbook and complete homework (24). Others linked their participation strictly to how much they contributed to the overall discussion (130). Students admitted that they only participated in a public manner when they were sure that they knew the correct answer (53), or never because they were shy (35) and some specifically stated that they participated more when the CRS was in use (49). A female student wrote: “I do not want to seem like I am trying to hog class time.” This idea of ‘hogging class time’ was also presented by other students in the metareflections.

The value of discussions as a learning activity is questioned by some. Comments include that discussions are confusing in that they cause individuals to ‘second guess’ themselves (28). Others felt that they learned the most from the discussions themselves (46). It seems that the use of a CRS caused at least some of the students to become more engaged in discussions. There are very direct statements to that effect, as well as statements that indicate students were listening and observing during non-CRS weeks, but participating in discussions during CRS weeks. However, statements indicating that some of the students would have preferred a more traditional classroom interaction go beyond whether they did or did not value discussions: several students wrote that they needed more in-class calculation practice specifically in preparation for tests (22), and that they preferred a straightforward 'telling' of what they needed to know (17).

The remainder of the comments fell into three categories: students missed class due to illness, or were in class, but felt ill (32); non-class related issues that had nothing to do with health, such as assignments in other classes took priority or family or work problems (84); comments that could not be interpreted (13).

Based on coding patterns across weeks, there appears to be a connection between how interested students are, how well they understand a topic, and how much they participate in classroom interactions. An additional component of this pattern developed in that several students rated their interest and participation across weeks where they sat closer to the front of the room or further in the back (6). All of these statements indicate that the further in the back these students sat, the less they participated and the more easily they detached themselves from the discussion.

Prompt 6: "If you used the 'clickers' (PRS) this week, did the use of the system influence your answers? And if so, how?"

Again, students' responses ranged from single word statements to two- or three-sentence statements. The 355 comments provided were coded into 23 open codes (see Table 4.22). The rules for why one or another comment was included in one of these categories are listed in the same table.

Table 4.22: Weekly Reflection Prompt 6; Open Code List and Code Rules

Code Number	Open Code	Code Rules
1	Group, missing	Direct statement that students missed their prior group members.
2	No	Single word response indicating that the CRS did not influence answers.
3	No and yes, my choice, but others' input	Direct statement that the student was ambivalent about the effects of the system.
4	No, anonymity	Direct statements that the student did not feel influenced by the CRS, but did appreciate the safety of an anonymous response.
5	No, but fun	Direct statements that the student did not feel influenced by the CRS, but thought using the system was making class more fun.
6	No, but more important input	Direct statements that the student did not feel influenced by the CRS, but thought that his/her input was more important with the system than without it.
7	No, discussion	Direct statements that the student did not feel influenced by the CRS, but that discussions were influencing what choice was made.
8	No, more participation	Direct statements that the student did not feel influenced by the CRS, but that overall participation increased when the system was used.
9	No, my choice	Direct statements that the student did not feel influenced by the CRS. Instead, the student felt free to vote according to his//her thinking.
10	Not clear	Statements that could not be interpreted.
11	Sick	Direct statements that students either had been or were sick, without offering any additional information.
12	Too much time	Direct statements that the use of a CRS was taking up too much time, without offering any additional information.
13	Yes	Single word response indicating that the CRS did influence answers.
14	Yes, anonymity	Direct statements that the student did feel influenced by the use of the system, specifically because of the anonymity it offers.
15	Yes, discussion	Direct statements that the student did feel influenced by the use of the system, specifically because of discussions.
16	Yes, more fun	Direct statements that the student did feel influenced by the use of the system, specifically mentioning 'fun' as qualifying statement.
17	Yes, more participation	Direct statements that the student did feel influenced by the use of the system. Includes statements indicating higher participation with the CRS, but not indicating anonymity or fun as criterion.
18	Yes, multiple choice provides more insight than open ended	Direct statements that students felt influenced by the use of the system. These addressed specifically the format of the anchoring questions.
19	Yes, my choice	Direct statements that the student did feel influenced by the use of the system, however, indicating that the student voted regardless

		of system use.
20	Yes, see histogram	Direct statements that the student did feel influenced by the use of the system. These statements indicated the histogram consideration as the mechanism of influence.
21	Yes, show confidence	Direct statements that the student did feel influenced by the use of the system. This addresses specifically the CRS's ability to let students indicate how confident they were in their responses.
22	Yes, think more	Direct statements that the student did feel influenced by the use of the system. Includes only statements that students felt that they thought more deeply about questions posed in connection with the CRS.
23	Yes, work harder	Direct statements that the student did feel influenced by the use of the system, because the CRS caused them to work harder than they would have otherwise.

A total of six axial codes resulted: anonymity, fun, more participation, discussion, choice, and other. Results of selective coding that integrates across axial coding are also part of the three-dimensional model, which is presented as the C^3 Framework (Chapter 5).

What follows is a listing of how often students made specific statements.

Students provided a total of 355 comments; of those 143 indicated that the system did have some influence on their responses, and 180 felt that it did not. The remaining 32 comments did not answer the question. Some student responses again were consistent across the sections.

Those who felt that the CRS did influence their responses often gave reasons that were linked to the safety of anonymous participation and to the aggregated feedback the histogram offered to all participants (62). Students indicated that the feedback influenced the direction of subsequent discussions which also were better qualitatively and more fun (42). Some felt that their choice was more informed by small group discussions in connections with the CRS than without it, stating that they were thinking more deeply, worked harder, and were generally more active participants in the process (30). The remaining statements simply agreed with the prompt without qualifying statements (9).

Student reasons for stating that the CRS did not influence their responses included that answers are based on knowledge, not technology, and to the prominent role of discussions in influencing choices of answers (33). Several stated that, while the CRS did not influence their answer, the anonymity it provided helped them to participate more actively (11). Two students indicated that they thought their input was more important with the system and one noted it was more fun to use CRS. The majority, unfortunately, did not provide any qualifying statements (133).

Some of the students in both sections thought that the use of a CRS was a waste of time, and that the process frustrated them (5). These feelings were also present in less direct statements; for example, some students indicated that they could not participate in their group discussions because others were more aggressive in their contributions. One student wrote that it is fairly easy to just sit back and tune out, since someone else in the group would still provide input.

Metareflections

At roughly mid-term, students were asked to submit a metareflection regarding their thinking about learning and teaching scientific content, their thoughts about the role of prior knowledge and participation, their attitudes towards CRS supported classroom interactions in IDS 3203, and how they would use such a system. The first five prompts provide a general background on how students think about learning and teaching science content, and as such are not specific to CRS use; the remaining two items, however, address specifically CRS use. The statements students provided to the seven prompts are listed individually below.

A total of 82 students turned in metareflections, 76 of them are female. Of those, 63 had identified themselves by ethnicity on other instruments. The majority of 34 are Hispanic, 24 are White, one is African-American, and four had reported “other” as their ethnic background. Where marked trends for either Hispanic or White female participants were apparent, those are added separately for a given prompt.

Prompt 1 (general background): “Has your thinking about learning scientific concepts changed in any way since the beginning of the semester? If so in what way?”

Students provided a total of 193 comments to that prompt, 188 of which were positive in nature. Three main ideas emerged from the analysis: (1) Over time, students became more interested in the content, and more confident in their ability to understand scientific ideas; (2) Students recognized that scientific concepts are anchored in the ‘real world’; (3) Students came to view science as something that was worthwhile and ‘fun.’

Prompt 2 (general background): “Has your thinking about teaching science changed in any way since the beginning of the semester? If so, in what way?”

Of a total of 152 comments, 135 were interpreted as positive. They either described a shift to viewing the teaching of science ideally as an engaging and fun activity, and as thinking of oneself as being confident to be able to teach science content. The 17 negative comments were either indicating that the student was not interested in teaching science, or were strongly linked to a traditional view of teaching. Specifically, these indicated that teaching science properly required algorithmic, fact-oriented methods and that teachers have to know all of the answers and cannot show any uncertainty.

Prompt 3 (general background): "If you could change anything in our course (IDS 3203), what would it be and why?"

The 131 comments were coded into two categories: (1) Physical setting (49 statements): Students would have preferred to be part of smaller class sections, to meet for longer periods per class meeting and in a room with tables rather than a lecture hall, in a room that would allow the instructor to come to visit with all of the students, not just those at the 'edges' of the seating area, and to incorporate lab and lecture into one course. (2) Mode of instruction (47 statements): Of those, 7 comments indicated that students would have preferred a more cooperative environment that should have included more group-based and hands-on components. However, 40 comments expressed a preference for a more traditional environment with more lecture and less discussion, with more 'structure' and more drill-and-practice type of problem-solving practice, and more homework assignments. Three of the female White students and two of the female Hispanic students wrote that they thought people were hogging class time during discussions. Students also submitted statements specific to the frequency of use of the CRS (18 statements): One of these indicated that a student would have preferred not to use the CRS all, however, the other 17 would have preferred to use the system all of the time.

The remaining 17 statements were scattered across a wide range of preferences, such as for example related to the textbook. Here, two statements indicated students would have preferred a different textbook, and another wrote that there should not be a textbook at all. With the exception of the two statements regarding textbook choice, all others were single occurrences.

Prompt 4 (general background): "How are you an important participant and guide in your own learning in this course? How could you be more in charge of your own learning?"

This prompt elicited a total of 172 comments. Of those, 114 responded to the first, and the remaining 58 to the second question.

Students responses to the first question can be categorized into two components, with the second one being addressed in overwhelming numbers: (1) General attitude (2 statements): Keep an open mind; (2) specific activities (112 statements). Sub-categories are (a) In-class activities (69 statements) that include specific actions such as taking notes, and more general participatory measures such as paying attention and asking questions; (b) Outside of class activities (43 statements) that were explicitly stated consist of reading the textbook, studying, and being part of a study group.

Amongst the identified female Hispanic (34) and female White (24) students, only White students noted that they participate through taking notes and paying attention (9). Both Hispanic and White students noted that they considered reading the book to be an important part of this aspect (8 White, 6 Hispanic).

The second question led to a total of 58 comments. Of those 14 addressed what students thought they should do during in-class time. These included having a better attendance record, and being a more active participant in class. The remaining 44 statements provided input on what students thought they should do outside of class. These ranged from more vague comments such as "should do more outside of class" to more specific thoughts, such as that they could work end-of-chapter problems, join a study group, read more carefully, or go to the tutoring lab.

Prompt 5 (general background): "In general, what role does prior knowledge play in your opinion? What role does YOUR prior knowledge play in YOUR learning?"

Student statements were categorized in two different schemes: the first is a coding of what view students have of prior knowledge as applicable to learning scientific content (76 statements); the other categorizes the specific types of knowledge students consider to be useful (65 statements).

Of the 76 statements regarding student interpretations of what constitutes prior knowledge, a surprising 50 were remarkably narrow. That is, these students thought only prior knowledge of formal science and mathematics was useful. Half of he remaining 26 statements indicated a broad view, and the other half could not be interpreted as being either narrow or broad.

Where students made specific comments regarding what prior knowledge helped, 65 in all, again 50 were content specific. That is, students thought that their prior knowledge in mathematics and science was helpful, and included the laboratory experiences in the accompanying laboratory course. The remaining 15 comments indicated that these students thought that life experience and attitudes in general make a difference.

Prompt 6 (CRS): "You have experienced class sessions in which we did use the clickers to collect responses, and you have experienced class sessions in which you were asked to respond by raising your hand. Write about whether and how the two different formats affect the following aspects: (a) your understanding of the concepts; (b) your participation in the discussion; (c) your feeling in charge of your own learning; (d) your feeling engaged in the learning process."

Student responses regarding understanding and feeling in charge of their learning were clearly attributable to the individual prompts. However, statements regarding participation and engagement were merged and thus will be reported together. In total, there were 329 statements for this prompt. Of these, 50 comments consisted of responses regarding understanding. Students vastly felt that the CRS did not influence their understanding (37 statements). However, 12 indicated that the CRS did support understanding in some manner, and one felt that raising one's hand would lead to better understanding. Unfortunately, that student did not identify why s/he thought so. A total of 37 responses addressed 'feeling in charge'; of these 13 stated that there was no difference regardless of use or non-use of a CRS. Whereas five statements indicated that raising one's hand gave a greater feeling of control, 19 statements attributed the same to the use of a CRS. The majority of comments, 242 of 329, addressed issues of participation and engagement when a CRS was in use. Only 19 of these were negative in tenor, and were coded into the following final categories: (1) traditional instruction preference (14 statements) include viewing the use of a CRS as gaming rather than learning, feeling that an emphasis on the group precludes individual learning, and that privately being wrong did not provide motivation for attempting to understand more deeply; (2) The second category consists of technology issues, such as difficulties to get the signal to register (5 statements). The other 223 comments to these sub-questions were positive. The majority of those addressed increased participation and engagement (214 statements) through safe participation in a fully anonymous classroom with the option to gain confidence through private evaluations. These comments also included valuing ways in which the CRS supported self-efficacy by providing opportunities to compare one's own understanding to the whole class, as well as to find out which concepts required additional work. The remaining nine comments indicated that students valued the feedback the system gave the instructor. One student wrote that questions asked with the CRS were more pertinent than those asked without the system.

Prompt 7 (CRS): "If you were the teacher of this course, how would you use this technology?"

This prompt received only a very few comments, 45 in all. Most of those agreed with the in-class use, however, some thought individual transmitter use would be more beneficial. In that condition, they felt the system would be well suited to collect attendance and participation data (14 comments).

Some comments to the metareflection prompts were unusual. They were coded into the categories above, but deserve special attention. Of these 27 statements, eight addressed perceptions of how worthwhile a question was. Students wrote that discussions were better with a CRS, that they put forth more effort and thus learned more in these interactions. Statements included that some of the students never responded to 'raise hand' questions, that they tried harder with the CRS, that the CRS itself 'feels like science,' and that the questions were more pertinent.

Eleven statements indicated that students held deeply traditional views. They felt that science is a collection of facts that can be learned without being engaged, and that talking did not help learning. Another stated that 'children need a sense of authority' in the classroom, a structure that traditional instruction provides. Interesting here is that comments by the group of identified Hispanic or White female students indicate two different trends: only one Hispanic female participant contributed a statement such as the ones listed above; White female students contributed all others.

Seven of the statements come from reflections that potentially contained contradictions. For example, students described how they used to love science in high school, but then stated that they did not remember anything they had learned there. Unfortunately, it was not clear what it was they loved about their high school science classes. If their experience was one that is typical of the Texas high-stakes testing environment, then their classrooms may have been very algorithmic and fact- and performance-oriented. The emphasis may have been on memorization rather than understanding, which would explain why they did not remember the science they purportedly loved.

Issues of inequities were raised in three of the statements, all of which are added verbatim below. One student wrote that High School science teachers focused more on male than female students:

> *Science has always been an interesting subject to me, but I had a bad high school experience with Physics. I just could not grasp the concepts. I truly believe it was partially me, but a lot had to do with the way the teacher taught. I believe he focused more on the males in the class then the female learning the concepts.* (African-American student)

Another student viewed his own cultural school experience as deficit:

> *One day in class, and before the first quiz a fellow student told me this stuff is easy. I don't even need a book or note taking materials. He further said you know, if you remember what you learned in high school this then is a simply a review. I suppose he's right based on his score on the quiz, 98%.*
>
> *Well, I was not as fortunate as he, my fellow student. I am a product of an inner city school with a predominant Hispanic population. And, in many cases we were steered into taking classes related to wood, metal, and mechanics (because we were slow learners) versus biology, math or science. I remember during my last three semesters of high school were mostly occupied with 3-4 periods of shop.* (Hispanic student)

The third statement was made by an English Language Learner who identified instruction in a foreign language as an additional difficulty:

> *This course has been a few confuse for me because the last time when I took something relates with Physics was twenty years ago and was in Spanish … I have had learning a lot of terms that for me the meaning is the same, but they are different in English such as speed and velocity for me both means "velocidad".* (Hispanic student)

Two of the remaining four statements contained indications that for some of the students there is no connection between everyday experience and science. Another two were specific to CRS use: one student stated rather categorically that a CRS is for group use, but without offering any explanation for why s/he felt that way; another thought of using CRS histograms themselves as learning objects, that is, to make interpretation of the histogram a learning task.

Summary

Results indicate that CRS use does not improve learning outcomes when comparing otherwise equal classroom interactions. While VASS results indicate that students' attitudes towards science hardly changed, reflection and survey data show that CRS use supported engagement and interest in discussion topics. Students appreciated anonymity as a condition that allowed safe participation. A detailed summary follows in Chapter 5, and conclusions are presented in Chapter 6.

CHAPTER 5

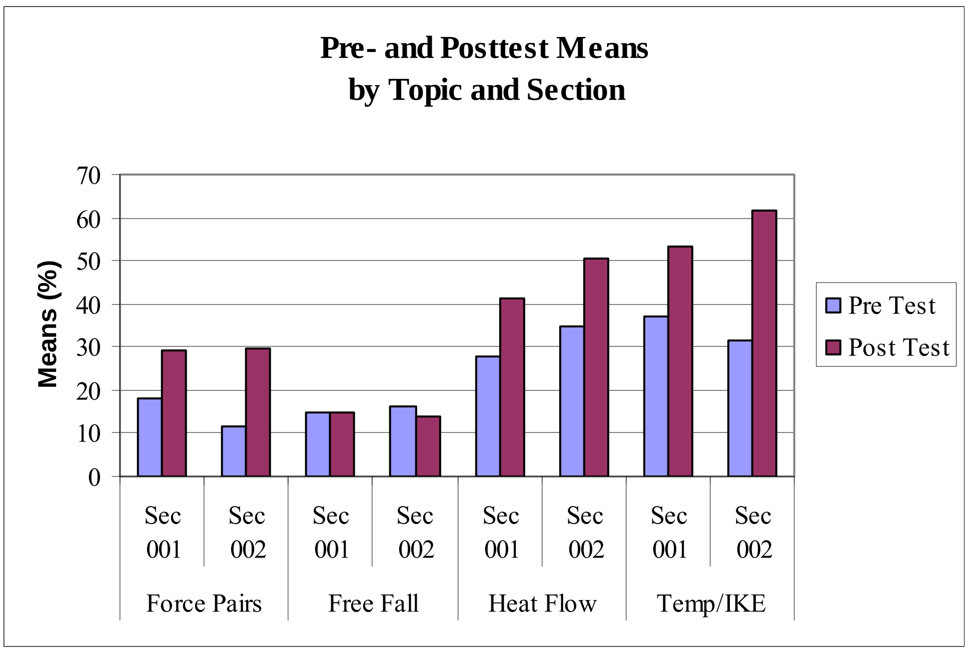
SUMMARY AND DISCUSSION

This study attempts to answer two questions: The first asks whether the fully anonymous use of a CRS leads to improved learning outcomes in a particular classroom interaction; the second inquires whether and how the use of a CRS impacts patterns of student attitudes and participation. Results are discussed in the same order.

Impact on Learning Outcomes as Measured by the Pre- and Posttest

Based on the CRS literature review, the author's expectation had been that use of the CRS would lead to a statistically significant greater gain in learning outcomes for the CRS group as compared to the non-CRS group for a given topic. In spite of the literature not addressing the specific learning environment of this study, there were strong indications that the level of intrinsic motivation increases with an engaging learning environment in which mastery goals are emphasized and frequent feedback is given. However, the literature also indicated that accountability might be essential for learning, an assumption that was set aside in this study. The tool provides such frequent feedback in an anonymous manner. The feedback itself focuses attention and scaffolds discussions by showing participants where they fall in the overall class understanding – increasing confidence levels and encouraging students to speak out. The researcher's assumption was that full anonymity would provide shy students with additional safety and thus additional opportunity to participate more actively in the learning process. As is evident from the literature review in Chapter 2, higher levels of participation are linked to better learning outcomes. However, none of the four subtopics indicated a statistically significant improvement of the CRS group over the non-CRS group. Figure 5.1 below summarizes pre- and posttest means for each of the four subtopics, as well as for each of the two sections.

Figure 5.1: Pre- and Posttest Means in Percent by Topic and Section



Each of the four subtopics had been tested with two questions, which means that outcomes are somewhat fragile. Although there were three statistically significant improvements amongst the four subtopics (force pairs, heat flow, and temperature/IKE), none were significant in terms of comparing the two groups. One way to explain this would be that the groups were not equivalent. However, results of the independent samples t-test of the pretest data indicate that there were no significant differences between the two groups on any of the four subtopics (see Table 4.1).

Another possible explanation is that the CRS was only one of several pedagogical tools employed to motivate students to think more deeply about the conceptual ideas presented in the course. That is, the CRS does support interactions and facilitate discussions, but discussions took place without it as well. This result is in agreement with results from the pilot study. Overall, the learning environment was structured as an interactive exchange of ideas, with an emphasis on small and whole group discussions, as well as frequent formative assessment opportunities. The instructor attempted to be ‘responsive’ to the direction the students’ discussions took and to thus apply the JiTT pedagogy described earlier. Although that means that the discussions were not identical to each other in content and sequence, the anchoring questions were identical for both groups.

Yet another possibility lies in the group-only response with full anonymity. Students had a potential ‘easy out’ during in-class discussions by either not participating in their small group discussion at all, or by deferring to others in the group. In those cases of passivity, students would not have experienced the benefits of peer learning. This link between anonymity and issues of non-accountability was recognized in the literature (see Chapter 2). However, anonymity was presented in the literature as having both beneficial and detrimental consequences. In regards to the pre- and posttest data, the lack of accountability may have had a dampening effect on learning outcomes.

The free fall sub-topic did not result in an improvement, but in no change for section 001, and a slight drop for section 002. All four of the means are within the ‘chance’ range of outcomes. The problem could be more deeply seated than understanding what constitutes a free fall condition rather, it may indicate a confusion of acceleration and velocity vectors. So, for example, the idea that faster velocities also indicate greater acceleration values could lead students to believe that the acceleration of a ball that is thrown downward is greater than that of a ball that is merely dropped. Similarly, believing that motion in a certain direction indicates a force acting in the same direction is a frequently applied naïve framework. These types of alternative conceptions are well documented in the literature (e.g., diSessa, Gillespie, & Esterly, 2003; Halloun & Hestenes, 1985a; 1985b; McDermott, 1984; Savinainen & Scott, 2002; Thornton & Sokoloff, 1990; Wandersee et al., 1994). The question is whether students held such alternative conceptions before instruction or adopted them during instruction, and what, if any, role the CRS played in the process.

There are indications in the CRS Survey data that students may have several ways of thinking about a process at a given time, which may or may not be activated depending on context; a finding that is also available in the literature (Kraus & Minstrell, 2002). Pretest results could be due purely to random selections, as they are within the chance range; posttest results may at least in part be due to students now having had exposure to distinctions between speed, velocity, and acceleration, and that the vocabulary itself activated certain ideas. If students had not yet successfully integrated what each of these represents, it is entirely possible that they still struggled with alternative conceptions stated above.

Regardless of which of these conditions applied, the fact remains that the instructor failed to detect the conceptual difficulty in both the CRS-supported and the non-CRS classrooms. In-class discussions of falling objects and of projectile motion on Earth indicated that students understood what force conditions needed to be considered. That is, after an object is in the air, it is only gravity that accelerates objects to the extent that air friction can be neglected. It is possible that the problem did not show up in the CRS section because the questions asked in class did not probe deeply enough whether students understood the difference between velocity and acceleration. The system can only provide feedback; the choice of question is the instructor's.

It appears that some students worked with two 'realities.' In response to the CRS Survey question on why they might make a choice against their 'common sense' most of the students who had agreed to do so in the first place indicated that they 'cannot think about these things in everyday ways' and that they thus had to put themselves in 'class mode;' they used one kind of rationale in the classroom and another outside of class. This lines up with findings of Minstrell's group, who report that students not only used different 'facets' of thinking in different contexts, but also may use several facets of thinking about one concept at the same time (Kraus &

Minstrell, 2002). Although the reviewed CRS literature did not indicate a similar finding, neither was there an indication that researchers probed that aspect.

Impact on Student Participation

Several data elements indicate that student participation was higher during times of CRS use; specifically, this was evidenced in the whole class video records and reflections. The trend is particularly prominent in weekly reflection data collected during the two weeks in which the CRS and non-CRS groups switched roles. Students who just started to use the CRS rated their participation compared to the prior week significantly higher than the group that just switched back to raising hands on the weekly reflection forms. Over the same period, there was an opposite trend in open-ended comments regarding participation. Students who just began to use the CRS had a roughly 40% drop in the occurrences of ‘traditionally oriented’ statements, while the other group scored a 7% increase in the same.

The difference in participation patterns is also apparent in the whole-class video records. Transcription and coding records indicate that CRS-supported class meetings led to more peer discussion in both small group and whole group segments. That is, the number of occurrences where students directly respond to another student’s comments is higher in CRS meetings than in non-CRS meetings. Possibly, this is linked to the public display of the aggregated histogram that may show others made the same choice and thus increase confidence. In addition, it is important to reiterate that students who were part of the initial CRS group reverted to ‘traditional’ lecture-hall behavior once they became part of the non-CRS group.

There is good evidence that full anonymity during CRS-supported class meetings contributed substantially to the observed increase in participation. As described above, student reflections clearly indicated that students appreciated safe and low-stakes formative assessment and feedback opportunities as provided by the system. Regardless of whether they thought the CRS influenced their answers or not, they felt that they could respond honestly without a fear of negative consequences.

Student Attitudes: Science

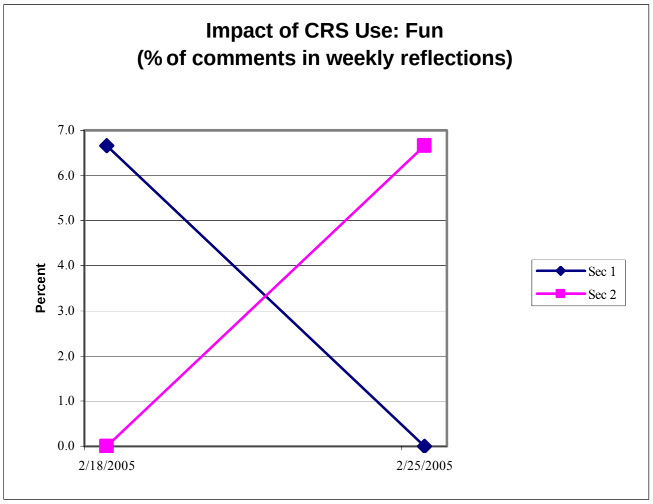
According to the VASS classification scheme, participants ranked in the folk and low transitional profile range. That is, their attitudes in the tested scientific and cognitive dimensions were mostly different from views held by experts. The developers of the instrument state that “students with a folk profile are primarily naive realists and passive learners” (Halloun & Hestenes, 1998). Since most of the students began the class with minimal knowledge about science, it is not surprising that their views are different from those of experts. It is also not surprising that they fell into the ‘passive learner’ category as most of their past formal educational experiences probably had been traditional and performance oriented.

Students had completed the VASS twice, once at the beginning and a second time in the middle of the semester. Overall, student scores were remarkably stable, a finding that is also acknowledged by Halloun and Hestenes (1996). Of the six criteria, only one showed a statistically significant change – the learnability score. Unexpectedly, the score dropped between the first and second data collection event. This finding is tempered, however, by other data elements indicating quite the opposite trend. According to the metareflections students turned in around mid-semester, students overwhelmingly viewed science as learnable and as interesting. Even though the picture painted by the CRS survey is not quite as rosy, it also indicates a positive stance regarding the learning of scientific concepts. Here, student responses suggest that they were interested in the topics studied, and that they felt they made important contributions to discussions. Since the VASS result is only slightly significant at the 95% level of confidence ($p = .042$), and since the finding is countered by data collected with other instruments, it is possible that the VASS result is not reliable.

Student Attitudes: CRS

While student attitudes towards the CRS varied, the majority of comments were positive. The main advantages of this technology as identified in the CRS literature were also recognized by students. That is, they appreciated the opportunities for anonymous participation offered by the system and enjoyed the feedback the histogram provided. Students also indicated that the use of the system caused them to think more deeply about the questions and that using the CRS was ‘fun’ and engaging. This is especially apparent in weekly reflection comments submitted during the two weeks where groups switched roles: Section 001, on 18 February still the CRS group, became the non-CRS group in the following week. Figure 5.2 shows how the role-reversal impacted student comments regarding how much ‘fun’ they thought discussions were. While the numbers are low and generalizations are at best tentative, the trends warrant further study.

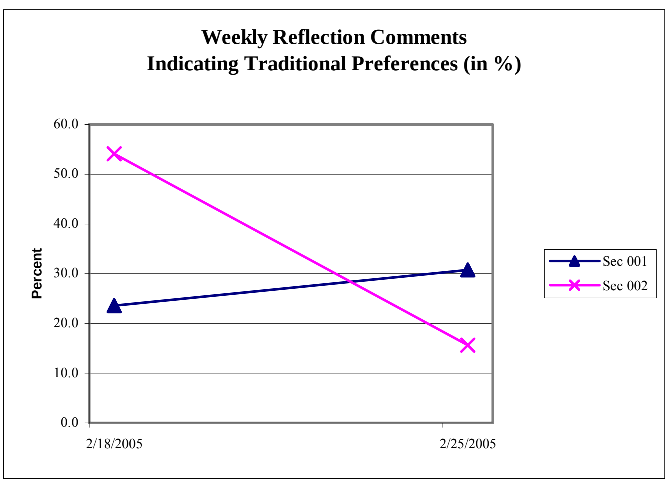
Figure 5.2: Percentage of Weekly Reflection Comments Indicating that Students Consider Lessons as Being 'Fun', weeks of 18 and 25 February only.



Although in the minority, students who held negative views of the CRS gave variations of the same reason for their attitude. Statements included that the system was 'a waste of time' and that this time would be more effectively spent on lecturing on specific facts they had to know for the test. Some commented that discussions were unnecessarily confusing them and asked for drill-and-practice components. One explanation may be grounded in the most prevalent educational practice at both the public school and university level, which, in essence, frequently provides a 'bulimic learning' experience. Since students who are accepted at an institution of higher learning are likely good at functioning within the parameters of their prior educational experiences, it is possible that they feel comfort in 'playing a game with familiar rules' – one they already know they are good at. Hickey, referring to research by Jimenez-Alexandre, Rodriguez, and Duschl (2000) and by Bloome, Puro, and

Theodourou (1989), describes the practice of ‘doing the lesson’ rather than ‘doing the science’ as an embodiment of procedural display (Hickey, 2003, p. 414). As such, the student whose identity is that of the successful scholar is by necessity a non-participant in authentic practice. It does make sense then that these students rated their participation as high and gave as reasons that they attended class meetings, took notes, and read the book, all of which are trademarks of the traditional ‘good student.’ Weekly reflection data from the two weeks of role-reversal provide a clear indication that CRS supported instruction is more likely to coax students away from traditional behaviors fueled by performance goals (Figure 5.3). Again, although the data are not strong enough to generalize with confidence, the trend warrants further study.

Figure 5.3: Percentage of Weekly Reflection Comments Indicating that Students Prefer Traditional Instruction, weeks of 18 and 25 February only.



As mentioned above, an additional pattern in student behavior emerged in section 001: Section 001 was initially the CRS group and then switched to become the non-CRS group after the mechanics discussions were completed. Rather than continuing with the extent of participation they developed during CRS supported class meetings, students reverted to more traditional and less openly participatory behaviors. That is, the tool increases public participation during its use, but it does not change behavior patterns beyond its use, at least within the timeframe of one single semester. Students indicated that they felt comfortable in the classroom with and without the CRS, but that alone does not appear to provide enough of a counter-balance to feeling shy and to worrying about the possibility of publicly being wrong. This implies that the tool builds only temporarily a more openly participatory community of learners.

As addressed in the literature review, Tannen (2004) and Benckert (2001) noted that female learners carefully monitor their own public participation to avoid the appearance of wanting to dominate the discussion. Six of the female learners in this study commented specifically on ‘hogging class time’ in their reflections. One wrote that her participation was limited because she did not wish to ‘hog class time’; five other female students complained that some of the other students were ‘hogging class time’ during whole-class discussions. Although this is only a small percentage of all of the participants, it is safe to assume that others may have felt the same way. Public participation in whole class discussion, especially in a large section, is doubly stressful for female learners: not only do they have to contend with the risk of public failure; they may have to consider violating internalized rules of social behavior. The CRS mitigates these concerns to some degree, as it provides a tangible starting point for discussion through the histogram and a way to speak, albeit in a limited way, without “hogging class time”; everyone is expected to click in, so clicking in is not “hogging time.” On the other hand, these same students may have felt reluctant to dominate in their small groups, or to demand the right to wield the clicker, for the same reasons. For the female student who monitors how much of the class time she spends on public responses, the option to send in a vote anonymously is not enough.

The C^3 Framework

As described earlier, the C^3 Framework emerged out of the preliminary study on how CRSs are used across institutions and disciplines. It was originally solely based on findings related to the instructor side of CRS use. Surprisingly, the picture that emerged out of the student data was similar to that which had emerged out of the faculty data. Student behavior is falling along the same three dimensions: centeredness (traditional – social constructivist), concerns (performance – mastery), and control of discourse. Yet, the student triangle is contained within the instructor triangle, as it is the instructor who decides how much s/he wants to share control over the discourse. Although this means that students can only react to the instructor’s parameters, they, too, can either open or close the discussion.

In terms of centeredness, some students preferred traditional instruction regardless of whether a CRS was used or not; others indicated that they thought the system should be used all of the time, which can be interpreted as a preference for a more participatory learning environment. The majority, however, shifted apparently seamlessly along the continuum depending on whether the system was used or not. This means that students in general accepted and adapted to the instructor’s choices, a skill undoubtedly practiced in many classrooms. On the instructor side, shifting along the continuum is more halting and sometimes does not occur at all. Since students come to the classroom with an acceptance of an asymmetrical power relationship, their willingness to adjust is generally expected. Gutiérrez noted this behavior:

> Most students come to class with a fixed idea of the roles in a classroom: the student as someone distinct from and inferior to the professor from whom important knowledge will be received; the professor as someone who will be recognized, at least initially, as an authority in an unequal power relation because there is no consciousness of mutual dependency. In this scenario, the effort to preserve student identity as consumer (someone who pays tuition and therefore expects teachers to perform) might be stronger than any other force, and the teacher remains in charge of the production of knowledge. (Gutiérrez, 2002)

Student shifts also occurred along the axis of procedural and learning concerns. Students were concerned with grades during times of CRS use as well as during times the CRS was not used. Yet, the number of comments regarding procedural concerns, which included requests for drill-and-practice segments and 'straight lecture,' both traditional practices, was higher during times of non-CRS use than with the system. At the same time, the number of comments indicating interest in the topics and deeper understanding increased when the CRS was in use, as well as those of feeling valued and important. To illustrate, the following are weekly reflection comments about participation from three female students in Section 002. The statements below are presented verbatim as submitted by students in two consecutive weeks, the weeks of role reversal; the first (a) was based on a non-CRS week, the second (b) on a CRS week:

Student 1: *(a) Mainly just listened and observed. (b) We had the opportunity to answer questions. There was a lot of thinking involved and really using the info that was provided.*

Student 2: *(a) This week, I didn't really speak up that much because I think that I understood pretty much of everything that we talked about and if I didn't I waited for others to ask. (b) I participated all the time as far as talking about the questions/scenarios and coming up with an answer.*

Student 3: *(a) I listened actively, took notes and considered the concepts discussed. I did not speak to class but participated in conversations with my group that I feel expanded my perspective, but I did feel that my input was valued by the instructor and my peers. (b) I discussed with neighbors, answered in class questions. I feel comfortable participating in this class.*

It seems that the use of a CRS in a discussion-based learning environment not only scaffolds public participation, but also increases perceptions of personal relevance and agency. This trend was, however, not apparent in the VASS.

The third component of the framework, control of discourse, is based on different questions for teachers and learners. Traditionally, the control is entirely in the hands of the teacher – the sage on the stage. The question for the instructor then is one of comfort: How much of the control of discourse can be shifted to the students while still maintaining control over other goals? Reasons may be linked to institutional culture, such as what good teachers should or should not do; to the level of content knowledge the teacher has, so that unexpected student questions may be viewed as a rich learning opportunity or as a threat to authority; or to the teacher's own learning experiences which, consciously or subconsciously, are models for his or her teaching.

On the student side, the question is different: How much of the control can I take on and still remain in my own comfort zone? The more the instructor attempts to share control of the discourse, the more of an issue this becomes. In a non-CRS environment, discussions may not involve more than a handful of students who are confident and outspoken. For the others, the mere thought of speaking up already creates a stressful situation.

Here, prior in-class and out-of-class experiences combine to create a pattern of behavior. The comfort zone is like a box within which the student acts – or like the proverbial shadow over which it is so hard to jump. For the shy student who does not like to speak up in class, and especially in a large class, it is easier to accept more control of the discourse with the CRS. S/he can discuss in a small group and then, through anonymous voting, influence the direction that the subsequent discussion takes. For some of the students, the CRS becomes a venue to muster up the courage and to ask or answer a question, a pattern that was evident in several of the student's weekly reflections. It seems that the CRS histogram plays a large part in this, as students reverted to their quiet roles when the CRS was not used in later class meetings.

Although the control dimension is primarily determined by the instructor, students also have options as to the degree to which they participate in the classroom discourse. As mentioned above, these options increase the more the instructor invites active participation. Students may either be willing to publicly engage in the conversation, or they may refuse to do so. Overall, as is the case with the instructor component of the C^3 Framework, the control of discourse dimension is ‘fed’ by the other two components of the triangle. That is, the more traditional students are, the more teacher-centered are their preferences and the more they are concerned with procedural issues. They favor the lecture, with the sage on the stage telling them what to write down and to practice for the test.

CHAPTER 6

CONCLUSION AND IMPLICATIONS FOR FUTURE RESEARCH

Conclusions

Use of a traditional CRS did not improve learning outcomes between sections when all other instructional components remained the same across the two sections studied. This may be due to the lack of accountability related to fully anonymous use.

The system positively impacted student participation, interest, and agency, as is stated in the CRS literature at large. It does support community-building efforts in the classroom, but these effects remain only in place as long as the system continues to be in use. As soon as the classroom reverts to a non-CRS environment, student behavior reverts to prior patterns of behavior. This may also be linked to full anonymity, as students feel safe to respond without negative consequences.

This work demonstrates that CRSs can be used effectively in fully anonymous and group-based modes if the goal is only to scaffold active, discussion-based learning environments. This is an important function for several reasons: (1) Learning is a socially mediated process and as such relies on 'intrapsychological' and 'interpsychological' components; active participation is essential for learning to occur. (2) Active and engaging classroom interactions are more likely to foster intrinsic motivation and mastery goal orientation. (3) Students who are shy and do not like to speak up publicly find that full anonymity becomes an entry point to more active participation; for at least some of the students it becomes a pathway to more public participation. (4) These systems provide a means for legitimate peripheral participation which is an inwards-bound trajectory, rather than the so-frequent outward-bound trajectory of marginal nonparticipation.

All of these benefits are critical for any active learning environment, regardless of discipline or age group. However, to make this experience first-hand is particularly critical for the pre-service teacher population as they will be teaching soon. Should their school districts adopt this technology in connection with a textbook, they will be better prepared to evaluate how they can and want to use these systems in their own instruction. If they only experienced the typical introduction given by publishing companies, they would most likely think of the tools as having only administrative benefits. Furthermore, pre-service teachers who had opportunities to experience a CRS supported learning environment may request that their future schools and districts purchase such a system in order to encourage more active participation.

As is widely recognized in the literature, teachers tend to follow models they experienced during their own studies. Thus it is important that they experience models of active learning environments and think about issues of control. There are currently few opportunities for students to participate in a way that will contribute to the class interactions while at the same time providing the safety of anonymity. CRSs do provide such an opportunity, and pre-service teachers who used such a system in this way are more likely to explore further possibilities

An additional benefit of a fully anonymous mode is that instructor frustrations with administrative overhead are almost completely eliminated. When the

CRS is not used to collect attendance data or grades, it does not matter whether each transmitter number is linked to a student name. The issue is where the instructor falls on the Control and Concerns dimensions of the C^3 Framework: if s/he is instructor-centered and performance oriented, then the likelihood that s/he will give up administrative types of benefits is less than if s/he is concerned with students' active participation and mastery. However, for an instructor who is not interested in taking attendance by CRS and who uses the system formatively, eliminating this frustration may mean that s/he will continue to use the system rather than abandoning it.

CRSs alone have not been shown to improve learning outcomes. Their effects are tied to the overall pedagogical approach used in connection with the system. It is also not sufficient to use the system for an introductory period only; they need to be used consistently over the course of a semester or year of instruction.

The C^3 Framework addresses both instructor and student aspects of classroom interactions. In both cases it is the interplay of concerns, centeredness, and control of the discourse that define the conditions of CRS use. However, the asymmetrical power relationship inherent in typical classroom interactions makes it necessary for students to be more flexible and more willing to adjust than it is the case for instructors.

Future Research

The study is based on work with a pre-service teacher population during a single semester of their course work. Although a variety of data were collected, they are generalizable only to similar populations. In addition, there were several methodological shortcomings: complete anonymity precluded data collection of in-class CRS responses that could have been linked to specific participants; the timeframe of the study consisted essentially of six weeks of instruction, a period that is likely too short to fully observe and measure the effects of the tool; each sub-topic was evaluated with just two questions, a greater number of items would provide a more reliable outcome; some of the students' comments indicated interesting trends, however, they were not frequent enough to generalize with confidence. Several studies are necessary to test the findings.

The first strand is a longitudinal study where the same student population is followed through several CRS classrooms throughout their undergraduate experience. These pre-service teachers should then be followed into their own classrooms to see whether and how they use a CRS or other mechanisms that enhance student participation over time, and how control of discourse plays out in these classrooms.

A second strand is a study that broadens the population base for the same type of interaction. That is, use the same strategies with other undergraduate majors, or with high school students.

Thirdly, timing of the treatment itself needs to be varied. Rather than collecting data only in the first half of the semester, it should be collected in only the second half or throughout to investigate whether students react differently to the tool.

Fourth, using the same instructional strategies, individual and small-group uses of the CRS need be compared. That is, maintaining the aspects of full anonymity, formative assessment, and JiTT while only varying whether responses are made individually or by small groups.

Fifth, comparison of individual CRS responses vs. show of hands, with all other aspects unchanged. In this condition, each student provides individual input that is anonymous to the class as a whole. In addition, the instructor would guarantee to record only the participation itself, not the choices made. Thus students would still experience full anonymity in the CRS condition.

Sixth, CRS benefits and limitations are of particular interest in connection with female and bicultural learning experiences. Rather than focusing strictly on traditional CRSs, future studies should also investigate next-generation technologies with this population.

APPENDIX A

CRS IMPLEMENTATION STUDIES

	Boyle, 1999	Bullock et al., 2002	Burnstein & Lederman, 2001	Cue, 1998	Davis, 2003
good management tool	X				
test results better or equal to traditional lecture		X			
better communication	X	X			
students: small group discussions are best part of CRS					
students: small group discussion better than whole group					
students prefer individual over group response					
better attendance		X		X	
higher participation, more engagement		X	X		
more interested	X		X		
more enjoyment (fun)			X		
more formative assessment					
instructor more aware, more responsive instruction	X	X			X
students self-monitor understanding, understand more				X	
anonymity; private accountability					X
no lasting change					X
improvements are not due to technology alone					

	Dufresne et al., 1996	Ganger & Jackson, 2003	Hall et al., 2002	Mestre et al., 1996	Nicol & Boyle, 2003
good management tool	X				X
test results better or equal to traditional lecture					
better communication	X			X	X
students: small group discussions are best part of CRS					
students: small group discussion better than whole group					X
students prefer individual over group response					
better attendance					
higher participation, more engagement	X			X	
more interested	X				
more enjoyment (fun)	X				
more formative assessment	X		X		X
instructor more aware, more responsive instruction	X		X		
students self-monitor understanding, understand more	X	X	X		
anonymity; private accountability					X
no lasting change					
improvements are not due to technology alone	X				X

	Paschal, 2002	Poulis et al., 1998	Reay et al, 2005	Woods & Chiu, 2003
good management tool				
test results better or equal to traditional lecture	X	X	X	
better communication				
students: small group discussions are best part of CRS			X	
students: small group discussion better than whole group				
students prefer individual over group response			X	
better attendance				X
higher participation, more engagement	X	X		X
more interested				
more enjoyment (fun)				X
more formative assessment	X			
instructor more aware, more responsive instruction				X
students self-monitor understanding, understand more		X		
anonymity; private accountability				
no lasting change				
improvements are not due to technology alone				

APPENDIX B

INSTRUMENTATION

Pretest and Posttest Questions

Force Pair Question # 1 (PI-FCI)

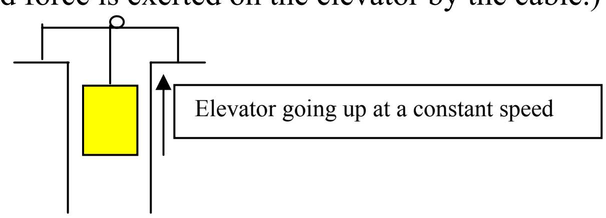
A large truck collides head-on with a small compact car. During the collision

a. the truck exerts a greater amount of force on the car than the car exerts on the truck.
b. the car exerts a greater amount of force on the truck than the truck exerts on the car.
c. neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
d. the truck exerts a force on the car but the car does not exert a force on the truck.
e. the truck exerts the same amount of force on the car as the car exerts on the truck.

Force Pair Question # 2 (PI-FCI)

An elevator is being lifted up an elevator shaft at a constant speed by a steel cable as shown in the following figure. All frictional effects are negligible. In this situation, forces on the elevator are such that

a. the upward force by the cable is greater than the downward force of gravity.
b. the upward force by the cable is equal to the downward force of gravity.
c. the upward force by the cable is smaller to the downward force of gravity .
d. the upward force by the cable is greater than the sum of the downward force of gravity and the downward force due to the air.
e. none of the above. (The elevator goes up because the cable is being shortened, not because an upward force is exerted on the elevator by the cable.)



Free Fall Question # 1 (FCI)

A boy throws a steel ball straight up. Consider the motion of the ball only after it has left the boy's hand but before it touches the ground, and assume that forces exerted by the air are negligible. For these conditions, the force(s) acting on the ball is (are)

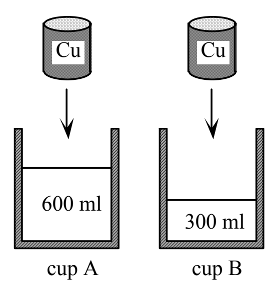
a. a downward force of gravity along with a steadily decreasing upward force.
b. a steadily decreasing upward force from the moment it leaves the boy's hand until it reaches its highest point; on the way down there is a steadily increasing downward force of gravity as the ball gets closer to Earth.
c. an almost constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point; on the way down there is only an almost constant downward force of gravity.
d. An almost constant downward force of gravity only.
e. None of the above. The ball falls back to ground because of its natural tendency to rest on the surface of the Earth.

Free Fall Question # 2 (PI-CT)

If you drop an object in the absence of air resistance, it accelerates downward at 9.8 m/s^2. If instead you throw it downward, its downward acceleration after release is

a. less than 9.8 m/s^2.
b. 9.8 m/s^2.
c. more than 9.8 m/s^2.

Temperature & IKE Question # 1 (Adapted UWash)



Two identical copper (Cu) cylinders are placed in styrofoam cups filled with water. Cup A is filled with 600 ml of water and cup B is filled with 300 ml of water. Initially each cylinder has a temperature of $90^{O}C$ and the water in each cup is at $30^{O}C$. ***Assume thermal interactions with the environment (air) are negligible in this problem.***
The final temperature of the water in cup A is

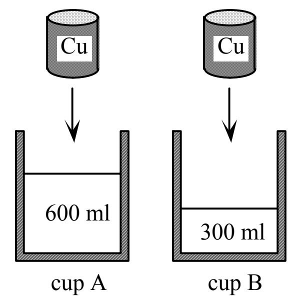
a. *greater than* the final temperature of the water in cup B
b. *less than* the final temperature of the water in cup B
c. *equal to* the final temperature of the water in cup B.

Temperature & IKE Question # 2 (Orig)

If you warm a cup of water from 50^o F to 100^o F, it is true to say that in terms of energy

a. the water now has twice as much.
b. the water now has more, but not necessarily twice as much.
c. the water now has the same.
d. the water now has less, but not necessarily half as much.
e. the water now has only one-half.

Heat Flow Question # 1 (Adapted UWash)



Two identical copper (Cu) cylinders are placed in styrofoam cups filled with water. Cup A is filled with 600 ml of water and cup B is filled with 300 ml of water. Initially each cylinder has a temperature of 90^{O}C and the water in each cup is at 30^{O}C.
Assume thermal interactions with the environment (air) are negligible in this problem.
The heat transfer from the copper cylinder to the water in cup A is

a. *greater than* the heat transfer from the copper cylinder to the water in cup B?
b. *less than* the heat transfer from the copper cylinder to the water in cup B?
c. *equal to* the heat transfer from the copper cylinder to the water in cup B?

Heat Flow Question # 2 (Orig)

You put one ice cube into a cup of water with an initial temperature of 50^o F and the water cooled to 40^o F. If instead you had put two ice cubes (same size) into the same cup of water, the water would have cooled to

a. 40^o F
b. 30^o F
c. somewhere between 30 and 40^o F
d. there is no way to predict this.

Views About Science Survey (VASS)

Thank you for taking this survey which is intended to identify factors that affect people's understanding of physical science, and to assist in the design of instructional material.
The survey was originally designed by Prof. Ibrahim A. Halloun in collaboration with Lebanese and U.S. researchers (Form P2B), and the Modeling Instruction research team at Arizona State University (Form C12). The two instruments were combined and adapted for an integrated physical science course by Carmen Fies.

All data are confidential. Your identity will not be disclosed to any party.
Your participation is voluntary and will be considered your consent to participate.

Please:
*Make **only one** selection per question item.*
*Do **not** skip any question.*
*Avoid guessing. Your answers should reflect what **you** actually and honestly think.*

Section I
Please answer each of the following 5 questions by choosing one of the provided alternatives.

1. By comparison to the rest of the class, how well can you understand the material presented in your current physical science textbook when you read it on your own?
A: Excellent; **B**: Good; **C**: Average; **D**: Weak; **E**: Extremely Poor

2. By comparison to the rest of the class, how good are you in solving homework physical science problems on your own?
A: Excellent; **B**: Good; **C**: Average; **D**: Weak; **E**: Extremely Poor

3. By comparison to the rest of the class, how well do you normally do in your current physical science course exams?
A: Excellent; **B**: Good; **C**: Average; **D**: Weak; **E**: Extremely Poor

4. How often do you read about science in newspapers, magazines, or books other than your current school textbooks?
A: More than once a week; **B**: About once a week; **C**: About once a month; **D**: Seldom; **E**: Never

5. How often do you watch science documentaries on TV?
A: More than once a week; **B**: About once a week; **C**: About once a month; **D**: Seldom; **E**: Never

Section II
In each of the following 10 questions, the two options labeled (a) and (b) are mutually exclusive.
*Please answer each question by choosing **only one** of the corresponding two options, (a) or (b).*

6. For me, reading my physical science textbook is often:
(a) an enjoyable experience.
(b) a frustrating experience.

7. If I had a choice:
(a) I would never take any physical science course.
(b) I would still take physical science for my own benefit.

8. If we want to apply a method used for solving one physical science problem to another problem, the objects involved in the two problems must be:
(a) identical in all respects.
(b) similar in some respects.

9. Different branches of physics, like mechanics and electricity:
(a) are related to each other by common principles.
(b) are separate and independent of each other.

10. Knowledge in chemistry is:
(a) related to knowledge in physics.
(b) independent of knowledge in physics.

11. Physicists and chemists say that electrons and protons exist in an atom because:
(a) they have seen these particles in their actual form with some instruments.
(b) they have made observations that can be explained by such particles.

12. Physicists' and chemists' current ideas about particles that make up the atom apply to:
(a) physical objects that could be anywhere in the universe.
(b) some physical objects in the universe but not others.

13. Newton's laws of motion (like his second law expressed in the form F = ma) apply to:
(a) physical objects that could be anywhere in the universe.
(b) some physical objects in the universe but not others.

14. Physicists' and chemists' current ideas about particles that make up the atom:
(a) will always be maintained as they are.
(b) may eventually be modified in some respects.

15. Newton's laws of motion:
(a) will always be used in their present form.
(b) may eventually be modified in some respects.

Section III
Each of the following 24 questions consists of two statements about a given issue, followed by five contrasting alternatives regarding the two statements. Please answer each question by choosing ***only one*** *of the corresponding five alternatives. The example below describes the five choices for question 16.*

Example

Learning physics requires:
(a) a serious effort.
(b) a special talent.

1. Mostly (a), rarely (b) **2**. More (a) than (b)
3. Equally (a) & (b)
4. More (b) than (a) **5**. Mostly (b), rarely

What would each one of the five choices mean?

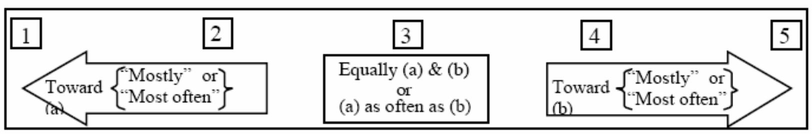
1. Mostly (a), rarely (b): Learning physics requires ***mostly*** *a serious effort* and ***rarely*** a special talent (or *mainly* the former and *hardly ever* the latter).

2. More (a) than (b): Learning physics requires ***more*** *a serious effort* than a special talent.

3. Equally (a) & (b): Learning physics requires ***as much*** a serious effort ***as*** a special talent.

4. More (b) than (a): Learning physics requires ***more*** a *special talent* than a serious effort.

5. Mostly (b), rarely (a): Learning physics requires ***mostly*** a *special talent* and ***rarely*** a serious effort (or *mainly* the former and *hardly ever* the latter).



16. Learning physical science requires:
(a) a serious effort.
(b) a special talent.

17. I study physical science:
(a) to satisfy course requirements.
(b) to learn useful knowledge.

18. Reasoning skills that are taught in physical science courses can be helpful to me:
(a) in my everyday life.
(b) if I were to become a scientist.

19. My score on physical science exams is a measure of how well:
(a) I understand the covered material.
(b) I can recall by rote things done by the teacher or in some course materials.

20. For me, doing well in physical science courses depends on:
(a) how much effort I put into studying.
(b) how well the teacher explains things in class.

21. In my opinion, for any question asked in class, a good physical science teacher should be able to:
(a) provide the correct answer.
(b) show how or where one may get the answer.

22. When I experience a difficulty while studying physical science:
(a) I seek help, or give up trying.
(b) I try to figure it out on my own.

23. When studying physical science in a textbook or in course materials:

(a) I find the important information and memorize it the way it is presented.
(b) I organize the material in my own way so that I can understand it.

24. For me, the relationship of physical science courses to everyday life is:
(a) easy to recognize.
(b) hard to recognize.

25. In physical science, it is important for me to:
(a) memorize technical terms and mathematical formulas.
(b) learn ways to organize information and use it.

26. In physical science, mathematical formulas:
(a) express meaningful relationships among variables.
(b) provide ways to get numerical answers to problems.

27. After I go through a physical science text or course materials and feel that I understand them:
(a) I can solve related problems on my own.
(b) I have difficulty solving related problems.

28. The first thing I do when solving a physics problem is:
(a) represent the situation with sketches and drawings.
(b) search for formulas that relate givens to unknowns.

29. In order to solve a physical science problem, I need to:
(a) have seen the solution to a similar problem before.
(b) know how to apply general problem solving techniques.

30. For me, solving a physical science problem more than one way:
(a) is a waste of time.
(b) helps develop my reasoning skills.

31. After I have answered all questions in a homework physical science problem:
(a) I stop working on the problem.
(b) I check my answers and the way I obtained them.

32. After the teacher solves a physical science problem for which I got a wrong solution:
(a) I discard my solution and learn the one presented by the teacher.
(b) I try to figure out how the teacher's solution differs from mine.

33. How well I do on physical science exams depends on how well I can:
(a) recall material in the way it was presented in class.
(b) solve problems that are somewhat different from ones I have seen before.

34. To me, physical science is important as a source of:
(a) factual information about the natural world.
(b) ways of thinking about the natural world.

35. The laws of physics and chemistry are:
(a) inherent in the nature of things and independent of how humans think.
(b) invented by physicists and chemists to organize their knowledge about the natural world.

36. The laws of physics and chemistry portray the real world:

(a) exactly the way it is.
(b) by approximation.

37. Physicists and chemists use mathematics as:
(a) a tool for analyzing and communicating their ideas.
(b) a source of factual knowledge about the natural world.

38. Scientific findings about the natural world are:
(a) dependent on current scientific knowledge.
(b) accidental, depending on scientists' luck.

39. As they are currently used, the Laws of Thermodynamics:
(a) are the same throughout the universe.
(b) change depending on where you are in the universe.

40. The Laws of Thermodynamics:
(a) will always be used as they are.
(b) could eventually be replaced by other laws.

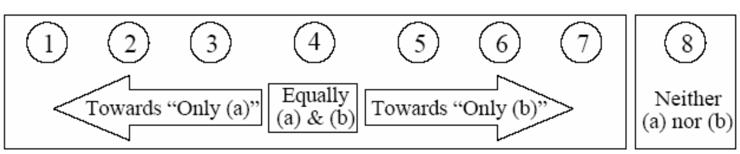
41. I answered the questions in this survey:
(a) to the best of my ability.
(b) without thinking seriously about them.

Example

Learning chemistry requires:
(a) a serious effort.
(b) a special talent.

What would each one of the eight choices mean?

① Only (a), Never (b):	Learning chemistry requires ***only*** *a serious effort* and ***no*** special talent *at all*.
② Mostly (a), Rarely (b):	Learning chemistry requires ***far more*** *a serious effort* than a special talent.
③ More (a) Than (b):	Learning chemistry requires ***somewhat more*** *a serious effort* than a special talent.
④ Equally (a) & (b):	Learning chemistry ***equally*** requires ***both*** a serious effort and a special talent.
⑤ More (b) Than (a):	Learning chemistry requires ***somewhat more*** a *special talent* than a serious effort.
⑥ Mostly (b), Rarely (a):	Learning chemistry requires ***far more*** a *special talent* than a serious effort.
⑦ Only (b), Never (a):	Learning chemistry requires ***only*** a *special talent* and ***no*** serious effort *at all*.
⑧ Neither (a) Nor (b):	Learning chemistry requires ***neither*** a *special talent* ***nor*** a *serious effort*.



VASS Dimensions

Dimension	Criteria
Scientific: Epistemology, Structure	***E1*** Science is a *coherent body of knowledge* about *patterns* in physical realities (real systems or phenomena), rather than a loose collection of particular empirical facts.
	E2 A given pattern is defined by a limited number of *primary* aspects *common* to a variety of physical realities, and not by a comprehensive similarity in all possible features that may actually be attributed to all concerned realities.
	E3 Primary aspects of physical realities, and especially *explanatory* or causal aspects, may need to be *inferred* from certain observations, and are not necessarily exposed directly to our senses or detectable through instruments.
Scientific: Methodology	***M1*** The methods of science are *theory-laden*, *systematic* and *generic,* rather than idiosyncratic and situation specific.
	M2 Natural patterns are usually *unveiled* by *careful investigation,* rather than discovered accidentally through direct perception of physical realities.
	M3 Scientists may follow a *variety* of *methods* and rely on a *variety* of *theories* to investigate a given physical reality from different perspectives, rather than on a single method governed by a particular theory.
	M4 Mathematics is used by scientists for processing information efficiently, rather than for mere number crunching.
Scientific: Validity, Viability	***V1*** Scientific *conceptions* (concepts, laws, models) are *invented* by scientists to represent physical realities in some respects; they are not necessarily inherent in the nature of such realities.
	V2 Every scientific conception has a *well-delineated function* within a particular scientific theory, but a *domain* that may extend to a multitude of physical realities throughout the universe. No two conceptions can serve exactly the same function, and no conception is generally restricted to localized realities.
	V3 Every scientific conception is *corroborated* with *reliable evidence* from the empirical world, rather than faithfully accepted from particular scientific authorities.
	V4 Scientific knowledge is *approximate, tentative,* and *refutable,* rather than exact, absolute and final.
Cognitive: Learnability, Readiness to Learning	***D1*** Science is *learnable by anyone* willing to make the effort, not just by a few talented people.
	D2 Achievement depends more on *personal effort* and *perseverance,* rather than on the influence of teacher, peers or textbook.
	Understanding favors: ***D3*** students who come to class with a prepared mind, rather than those who study only after the teacher covers materials in class,
	D4 and those who seek scientific information from alternative sources and discuss it with peers, rather than those who stick to the textbook and their own ways of doing things.
Cognitive: Reflective Thinking	For meaningful understanding of science, one needs to: ***T1*** concentrate more on the development of *generic methods* for *construction* and *deployment* of scientific ideas, rather than on memorizing facts and procedures;

	T2 model a situation and investigate it in *many ways*, instead of relying exclusively on a formula-centered approach;
	T3 continuously *evaluate* one's own work for *consistency* and *effectiveness,* instead of just accumulating new information from presumed authorities;
	T4 *reconstruct* new subject knowledge in one's own way while delineating its *scope,* instead of memorizing it as given and without realizing its viability conditions.
Cognitive: Personal Relevance	***R1*** Science is *relevant to everyone's life.* It is not of exclusive concern to scientists.
	R2 Studying science should be an *enjoyable* and a *self-satisfying* experience, rather than a frustrating one undertaken to satisfy curriculum requirement and other people's expectations.

Classroom Response System Survey

1. How did the feedback through the histogram influence your study behavior in this class?
    a. Helped me to focus on topics where I needed more study time.
    b. Made me aware of where my understanding falls compared to the class.
    c. Built up my confidence level.
    d. Lost my confidence.

2. If you purchased the transmitter, which of the following did you consider being most beneficial?
    a. Receiving credit for attendance.
    b. Additional incentive to be in class.
    c. Having many opportunities to collect points for the grade.
    d. Having my own transmitter made me feel more in control of the process.

3. If you were given a second opportunity to make a selection, did you tend to select whichever option was the most frequently selected in the first round?

4. Did you at any time during the semester make a selection because you thought it was the response your instructor wanted to hear even if your common sense told you that another option was the correct one? (Yes, No)

5. Rate the following as possible reasons why you might have made a choice against your 'common sense':
    a. I am never right in this class, so I pick what I think is the least likely correct answer.
    b. I've only done that when the concept was very counter-intuitive.
    c. I cannot think about these things in everyday ways, so I put myself in 'class-mode' and try to answer the questions based on what I read and heard in class only.
    d. I have a pretty good understanding of when my common sense works or does not work in class.

6. Please indicate the degree to which you agree or disagree with the following statements.
    a. I understand the ideas presented in the course.
    b. My input to in-class discussions was important and valued.
    c. I participated in every class session.
    d. I was interested in the ideas presented in this course.

NOTES:

1. All but question 4 were answered in a 5-point Likert scale (strongly disagree, disagree, neutral, agree, strongly agree)
2. Set 5 was only to be answered if the response to #4 was "yes"

Weekly Reflection Prompts

Please PRINT your name: ____

1. My understanding of this week's class discussions is
   a. Very good
   b. Good
   c. Weak
   d. None

2. This week, I felt that my input was
   a. Very important
   b. Somewhat important
   c. Not very important
   d. Completely ignored

3. This week, I felt that I participated
   a. All of the time
   b. Most of the time
   c. Every now and then
   d. Not at all

4. My interest in class this week was
   a. Very high
   b. High
   c. Low
   d. None

5. Explain why you responded the way you did regarding your participation:

____
____
____
____

6. If you used the 'clickers' (PRS) this week, did the use of the system influence your answers? And if so, how?

____
____
____
____

Metareflection Prompts

1. Has your thinking about learning scientific concepts changed in any way since the beginning of the semester? If so in what way?

2. Has your thinking about teaching science changed in any way since the beginning of the semester? If so, in what way?

3. If you could change anything in our course (IDS 3203), what would it be and why?

4. How are you an important participant and guide in your own learning in this course? How could you be more in charge of your own learning?

5. In general, what role does prior knowledge play in your opinion? What role does YOUR prior knowledge play in YOUR learning?

6. You have experienced class sessions in which we did use the clickers to collect responses, and you have experienced class sessions in which you were asked to respond by raising your hand. Write about whether and how the two different formats affect the following aspects:

   a. your understanding of the concepts;
   b. you participation in the discussion;
   c. your feeling in charge of your own learning;
   d. your feeling engaged in the learning process.

7. If you were the teacher of this course, how would you use this technology?

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