Increasing Conceptual Understanding in High School Physics Classrooms

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When students encounter academic difficulties, educators understand that they need to respond by developing strategies that target the deficiencies. In my high school physics classroom, most students are able, after instruction, to satisfactorily solve open response, multi-step calculation problems. However, their inability to articulate overarching physics concepts as they apply to such problems has been an ongoing concern of mine. As I examined my curricula, I found that it lacked significant time for students to think about the larger, "non-calculator" applications of the discipline. My goal was to increase conceptual understanding of physics by increasing opportunities for active discourse within in my courses. In order to be effective, I also needed some way to engage and motivate *all* students, not just a select few.

At the start of the 2008-2009 school year, I implemented the use of a "clicker system" in my classroom as a means of achieving that goal. In this new strategy, students are initially asked to individually respond to a multiple-choice "clicker" question that can be completed without a calculator; all students are required to respond and to be able to defend their choice. A tally of responses is compiled in real time and projected to the class. Students then engage in active discourse among themselves, reconsider their own answer to the same question, and are given the opportunity to change their initial answer if they so choose. The cycle is completed with a whole-group discussion of the correct approach and answer. The cycle occurs approximately every 15 minutes within any time spent in lecture.

To analyze the effects of the intervention, I examined pre and post intervention data, including comparing my students' overall scores on the nationally administered AP Physics C:Mechanics exam as well as their score on the more conceptual multiple-choice section of the same exam. I also compared scores on the Force Concept Inventory for both my Honors Physics students and my AP Physics students. Results indicate that the intervention was clearly successful with AP Physics students. Honors Physics students, however, show no statistically significant improvement in test scores.

Prior Research

This study's goal was to increase students' conceptual understanding of physics through the use the active teaching strategies of peer collaboration and self-explanation that are framed around the use of personal response systems. Though the effects of clicker systems in post-secondary environments has been studied (Hoekstra, 2008; Hatch, Jensen, & Moore, 2005; Stowell & Nelson, 2007; Yourstone, Kraye, & Albaum, 2008) current research is deficient in studies directly related to secondary school environments. Student self-explaining, specific to the field of physics, has been researched (Hausmann & VanLehn, 2007a; Hausmann & VanLehn, 2007b; Hausmann, van de Sande, & VanLehn, 2008) but has yet to be linked to improved understanding of overarching physics concepts. Likewise, peer collaboration has been thoroughly studied (Smith, Wood, Adams, Wieman, Knight, Guild, & Su, 2009) but not yet linked to physics instruction with clickers in a secondary classroom.

Student Response Systems

Personal response systems ("clickers") are a relatively new technological innovation at the secondary level. Most prior research on the effects of clickers has been conducted at the post secondary level; however, results obtained in such settings should be consistent with use in a high school classroom.

Clicker systems record and save individual student responses to any question posed, compiling overall results and displaying them in real time after all students have responded. Research confirms that this structure provides a means for instructors to motivate students to actively participate throughout the class (Hoekstra, 2008). Stowell and Nelson (2007) compared formal participation rates for students in four settings: (a) a traditional lecture, (b) a lecture that integrated handraising, (c) a lecture that integrated response cards, and (d) a lecture that integrated a clicker system. The highest rate was found with clicker systems, where 100% of students participated. Because the technology creates a truly anonymous polling of student ideas, even the most shy or uncertain student can safely participate without fear of looking stupid to their peers (Paschal, 2002).

Simple participation, though, does not guarantee cognitive engagement. Draper and Brown (2004) surveyed college students who had experienced questions in lectures that demanded either a verbal response, use of a personal response systems, or hand-raising. When these students were asked *'When are you more likely to actually work out a problem posed in class?;* the majority either said that they always worked out the answers (20.6%) or that they were most likely to work out the answer when voting with the personal response systems (32.4%). This response is more revealing than the simple participation statistic reported in the previous paragraph; these finding show that not only do students utilizing clicker systems decide upon and report answers, but they also engage mentally to attempt to reach *correct* answers. The resulting active learning has been shown to improve many learning skills, including critical thinking skills, the transfer of content to new situations, and motivation (Premkumar & Coupal, 2008). Suggested alternatives to clicker systems, including color coded cards and hand-raising, are prone to students' copying the most common answer (Gauci, Dantas, Williams, & Kemm, 2009); because there is no accountability to these systems, students tend to put forth less effort when attempting to arrive at correct answers.

The feedback provided by clicker systems also benefits the instructor in that she is provided an immediate and fair evaluation of the degree of student understanding, allowing her to focus and adapt the flow of the lesson appropriately. According to Paschal (2002), college professors who integrated clicker systems into their lectures reported that the histograms provided by the technology allowed them to correct misunderstanding rapidly, to review content that students were finding particularly challenging, and to spend less time on material that students already had a good understanding of. Appropriate remediation is also possible because the feedback provided by clicker systems better represents true student knowledge than the feedback an instructor gets when students are asked to raise their hands, presumably because hand-raising is more strongly tied to social conformity (Stowell & Nelson, 2007).

Self Explanation

According to Hausmann and VanLehn (2007b), "during self-explaining, the student is engaged in an active learning process, which includes accessing prior knowledge from long term memory, using common sense reasoning, employing sense-making strategies, and doing so from their own background knowledge" (p. 1068). The process of self-explains requires purposeful integration of old information with a new problem, resulting in a deeper understanding of the material being covered and its connection to other content (Chi, De Leeuw, Chui, & Lavancher, 1994). Chi (2003) further expanded on this view, explaining that another powerful aspect of self-explaining is the need for students to actively repair their mental models when they discover that their ideas are disparate from new and/or correct knowledge (as cited in Atkinson, Renkl, & Merrill, 2003). Webb (1989) found that providing elaborate explanations was correlated to significantly increased student achievement, whereas receiving elaborate explanations correlated with only mild increases in achievement (as cited by Chi et al., 1994).

One concern related to self-explanation is the effect that *incorrect* student self-explanations might have on learning. Chi et al. (1994) found that incorrect self-explanations were not found to be detrimental to learning. "An incorrect self-explanation merely objectifies that piece of knowledge, which allows it to be examined in the face of conflicted information from subsequent sentences, thus establishing the opportunity for self-repair to resolve the conflict" (p. 33).

Peer Collaboration

Peer collaboration is a valued learning technique because of its reliance on social constructivism (Nicol & Boyle, 2003). Students working together are able to build upon their combined knowledge and feel an obligation to stay motivated and committed to their shared goal. The active engagement encouraged by peer collaboration leads to an increased ability to reason out both conceptual and quantitative problems without the assistance of an expert (Crouch & Mazur, 2001). Talking with peers has been found to help students who do not understand a principle, even if the peers are only in the early stages of comprehending the principle (Mazur, 1997).

Peer collaboration is believed to improve learning for several reasons:

1. Because it is social, students practicing peer collaboration remain engaged in the content and are challenged to figure it out by themselves (Hausmann et al., 2008; Nicol & Boyle, 2003).

2. Discussions among students aid in the interpretation of questions, which leads to an increased ability of students to choose the correct approach to a problem (Yourstone et al., 2008). Peer discussions help students think through problems and discover alternative approaches to a solving a problem (Nicol & Boyle, 2003).

3. When multiple perspectives are present, the group is forced to compare and contrast the different interpretations to arrive at what the group believes is the most logical approach and answer (Nicol & Boyle, 2003). This metacognitive process aids both in making connections and in creating a bridge between the content and the application of the content to unique problems.

4. Peer collaboration helps to clarify misunderstandings when the authority figure does not make sense from the students' perspective (Hausmann et al., 2008).

Peer collaboration techniques used in combination with a student response system have been studied at the post-secondary level. Student response systems cause students to become more engaged in peer collaboration than when the response systems are absent (Yourstone et al., 2008). To realize the greatest benefit, peer collaboration should be structured, including providing some form of a script during early attempts (Nicol & Boyle, 2003). Thus far, the most effective structure found has been: (a) pose the question, (b) allow for individual thinking and response, (c) provide feedback in the form of a histogram of student responses, (d) allow time for peer discussion, (e) re-poll student responses, (f) provide feedback in the form of a histogram, and (g) review the question, approach and answer within a whole group discussion, being sure the instructor clearly identifies the correct answer.

Most participants in the above-mentioned study reported that dialogue with other students in peer groups was central to developing clear understanding of concepts (Nicol & Boyle, 2003).

All participants also agreed, though, that it was "important that the teacher clearly explains which is the right answer and why" (p. 466).

Methodology

Participants in this study were all students enrolled in either my AP Physics C or Honors Physics courses, from September 2006 to the present, involving a total of 50 AP Physics students and 71 Honors Physics students. None of these students has had a prior course in physics. Two of these students were in their junior year of high school, while all of the rest are in their senior year. When enrolled in my class, most intended on pursuing post-secondary degrees that required them to take courses in physics (such as engineering, the physical sciences, or medicine). The author, who has 19 years of experience teaching physics and four years of experience teaching AP Physics C, was the course instructor.

The classroom used for the course is equipped with a Student Response System marketed by Turning Technologies. The system consists of 24 infrared clickers and a portable receiver that can be used with any computer. The system requires the instructor to design multiple-choice questions within PowerPoint presentation slides. When such a slide was presented to the class, students were required to work the problem individually, recording their final answer with their personal clickers when they decided both on an answer and a justification for that answer. When all students had responded, results were projected to the class as a histogram. If the results indicated significant difficulties and/or misconceptions, students explained and discussed their approach and answers in small groups, followed by re-polling. All problems concluded with a review of the possible approaches and correct solution, presented either by the instructor or by students within a whole group discussion. As was the practice prior to the intervention, a wide variety of hands-on introductory and application activities precede and follow each lecture session, allowing student ample opportunity to explore the ideas presented.

Several measures were used to assess the effect of the strategy: anecdotal evidence was recorded by the instructor to gauge quality and quantity of participation and motivation. In addition, this study utilizes two sources of factual data: the Force Concept Inventory and the nationally administered AP Physics C:Mechanics exam. The Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1995) is a standardized test of basic Newtonian physics consisting of 30 multiple-choice, conceptual questions. For over a dozen years now, students in my physics courses have completed the FCI first at the beginning of the year (prior to instruction in Newtonian physics), and then again at the end of the instruction relating to Newtonian Physics. Therefore, the effect of the clicker teaching strategy on student's conceptual understanding can be assessed by comparing the post-instruction FCI scores of students in the years prior to introduction of the clicker strategy vs. students' scores since the introduction of the clicker strategy. Normalized gain scores (G), another measure of increased learning, were also compared.

In AP Physics, a convenient and standardized measure of understanding exists in the exam administered by the College Board. The AP Physics C:Mechanics exam consists of two sections: a constructed response section which focuses on multi-step, calculator-driven problems, and a multiple-choice section focused on more conceptual questions that must be completed without a calculator. Historically in my classroom, students have scored above average on the constructed response section of the exam but have floundered on the multiple-choice section. Scores from the multiple-choice section of the AP exam were compared both prior to and in the time since implementing the intervention. Finally, the AP exam itself is a measure of students' ability to articulate their understanding of physics; overall scores over the past 4 years are reported and compared.

Results

Anecdotally, students in both classes seemed more engaged and invested in discussing their ideas about physics when the subject of that discussion was embedded in the intervention described. Most often, the instructor offered no assistance in arriving at the correct answer; instead students consistently took the initiative to engage a majority of the students in the room in a debate about the approach and logic involved in the question at hand. After the debate, students most often came to consensus on the correct answer to the displayed question. Occasionally, though, the consensus answer was incorrect. In either case, listening the students as they discussed their thoughts with their peers provided valuable information to the instructor, either by giving confidence that the major concepts being addressed were understood, or by singling out the major misconception(s) that existed, allowing those misconceptions to be immediately remediated.

Anecdotal observations, of course, are no substitute for factual data. Four years of FCI data for Honors Physics students, and five years of FCI data for AP Physics students, are shown in Table 1 (see Appendix A); please note that data from the current year is absent for Honors Physics because at the time of writing, students had not yet finished instruction related to all content covered on the FCI. Values shown include the number of students in the course, the FCI class average prior to instruction, the FCI class average after instruction, and the average normalized gain, *G*. Honors Physics students showed very slight improvement when two years of data (pre- and post-intervention) are compared; overall average *G* pre-intervention was .465 while the post-intervention average *G* was 0.475. Though the average *G* increased, the increase is not statistically significant.

Data related to AP Physics students show more promise. The overall pre-intervention average *G* score was .59, while the post-intervention average, including the current year, has increased to .76 – a statistically significant increase. To further support increased understanding of conceptual physics concepts, the average of my students' overall scores on the AP Physics C:Mechanics exam (Table 2 of Appendix A) have risen: 3.315 vs. 3.510. Additionally, results from the multiple-choice portion of the AP Physics C:Mechanics exam (Table 3 of Appendix A) show dramatic increases: while fewer than a quarter of my students (average: 21.25%) scored above the median score pre-intervention, a majority (average: 51.55%) scored above the median post-intervention.

Implications for the Improvement of Practice

The results of the study indicate a clear link between the intervention and the desired goal within the population of AP Physics students. Because AP Physics courses must follow a somewhat prescribed curriculum, the content and activities that students performed from year to year were nearly identical except for the introduction of the clicker system intervention. It is worthy of noting, however, that the instructor has been teaching AP Physics for only 5 years, and that a portion of the gain shown by the data could possibly be a result of the instructors' increased confidence and skill. Even so, the author believes that the consistent and profound increase in performance, particularly on the FCI and on the multiple-choice portion of the AP Physics C:Mechanics exam, supports the positive effect of this study's intervention. The AP Physics students enthusiastically embraced the idea of peer discussion and self-explaining, and were highly motivated by what they perceived as a "fun, new technology", resulting in increased understanding and articulation of overarching physics concepts. These results clearly support the ongoing use of this technology with the AP Physics C:Mechanics curriculum.

However, a similar positive effect within Honors Physics students is not apparent given the data collected. The only available source of factual data (FCI scores) thus far show statistically insignificant gains in understanding. Anecdotally evidence, though, suggests that Honors Physics students are more engaged and motivated when immersed in the intervention process, and discussions were often rich and lively – a marked improvement over pre-intervention discussions. That being the case, the clicker technology and related active learning strategies still have value in Honors Physics.

Questions remain as to why success of the intervention seemed to be dependent of the level of the course. Notably, while the AP Physics curriculum remained relatively static throughout the years reported in this study, the Honors Physics curriculum experienced some other changes that occurred simultaneous with the introduction of the intervention, including shifting the primary mode of inquiry within the course to the modeling process. Therefore, it is possible that the positive effects of the intervention may have been masked by negative effects of other changes within the curriculum of that particular course. Alternatively, AP Physics students may have had greater success with the intervention because they entered the classroom with a higher degree of motivation to truly master the content and a more proficient ability to "think scientifically". Future research should therefore focus on isolating the effect of this intervention at all levels, and on modifying the intervention to benefit less-able students as much as more-able studnts.

APPENDIX A

Table 1: Force Concept Inventory Results

Course		Year	Number Students	Pre-test % Correct (before instruction)	Post-test % correct (after instruction)	*G*
Honors Physics	Pre-Intervention	2006-2007	18	23%	57%	.44
		2007-2008	16	28%	64%	.49
	Post-Intervention	2008-2009	16	24%	58%	.44
		2009-2010	21	28%	65%	.51
AP Physics	Pre-Intervention	2006-2007	10	35%	69%	.53
		2007-2008	8	34%	78%	.65
	Post-Intervention	2008-2009	12	30%	83%	.77
		2009-2010	13	28%	81%	.70
		2010-2011	7	43%	90%	.82

Table 2: OVERALL SCORES on the National AP Physics C: Mechanics Exam

	Year	Overall Average Score (on a 1-5 scale)
Pre-Intervention	2006-2007	3.00
	2007-2008	3.63
Post-Instervention	2008-2009	3.33
	2009-2010	3.69

Table 3: Scores on MULTIPLE-CHOICE PORTION of the AP Physics C: Mechanics Exam

	Year	% students scoring below the median multiple-choice section of the exam	% students scoring above the median multiple-choice section of the exam
Pre-Intervention	2006-2007	70%	30%
	2007-2008	87.5%	12.5%
Post-Intervention	2008-2009	58.4%	41.6%
	2009-2010	38.5%	61.5%

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