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A QUASI-QUALITATIVE ANALYSIS OF TIME-COMPRESSED SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS COURSE PEDAGOGY

A Thesis in

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Abstract

The number of time-compressed, or length-shortened, college courses continues to rise. The appeal of these courses began with the desire to accelerate learning, but has grown to include making use of typical university and college down time, including weekends. Research has demonstrated that there are best practice pedagogical techniques designed specifically for this type of course that lead to good learning experiences. The science, technology, engineering and mathematics community has also begun to utilize courses that are shorter than traditional length courses. Best practice pedagogy for these courses is still a hotly contested topic and much research remains to be done. Using a deep literature review of both time compressed and science course pedagogy, a series of suggested pedagogical practices are discussed. Their application to two time-compressed summer physics courses is qualitatively examined and found to be in good agreement with previous reported results in terms of learning outcomes, and instructor and student satisfaction.

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Abbreviations

ALPS – Active Learning Problem Sets

CATs – Classroom Assessment Techniques

CI – Competence Index

FCI – Force Concept Inventory

H&H MDT – Halloun and Hestenes Mechanics Diagnostic Test

IE – Interactive Engagement

IL – Inquiry Learning

MBT – Mechanics Baseline Test

PBI – Peer Instruction

PBL – Problem-Based Learning

PSU – Pennsylvania State University

STEM – Science, Technology, Engineering, and Mathematics

TC – Time Compressed

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Dedication

To all my teachers, past and present.

Chapter 1: Introduction

1.1 The Time-Compressed Course

Intensive, time-compressed (TC) courses, typically one-half or one-quarter the length of a traditional semester course, are now a mainstay at most universities. From their humble beginnings in the 1800s, to their overwhelming popularity today, these courses are cherished as a means to engage in the same material as a full-length course, but in a reduced timeframe.

The question of how to teach such courses effectively has always been at the core of utility arguments concerning them, but only in the last twenty years, as the number of offered intensive courses ramps up, has the effort to evaluate pedagogical approaches to the courses intensified. Furthermore, the effort to determine best practices in Science, Technology, Engineering, and Mathematical (STEM) TC courses, which have historically lagged efforts in other areas, has begun to yield results and understandings of what is necessary to create the desired learning experience.

Overall research in the area of STEM pedagogy has demonstrated that traditional methods of instruction seldom produce the kind of learning experience necessary to understand the rather difficult subject matter contained in STEM courses. As a result, new methods have been developed that make use of demonstrated pedagogical successes involving active teaching methodology. Studies of applying active learning to STEM courses have demonstrated amazing results, especially when compared to traditionally taught courses.

Evidence indicates that these methods of instruction are quite necessary when teaching a TC-STEM course. Much research remains to demonstrate best practice in the area TC-STEM course pedagogy. The following study examines the application of a combination of general

STEM course best practice pedagogy, as well as, TC best practice pedagogy to TC-STEM courses.

1.2 Origins and Evolution

Born out of utility, time-compressed courses owe much of their early influence to teaching institutes in the 1830s. It was there that the need to regularly and quickly update the skill sets of elementary and secondary school teachers was first established as requiring a new type of course that could be offered during the summer and winter intersession periods when these instructors' typical teaching duties were reduced. These courses needed to offer similar content and learning experiences in a four-week period instead of a traditional sixteen-week period [1].

After the American Civil War, Harvard University and Johns Hopkins University would begin the trend of offering a summer session utilizing time-compressed courses, first as a refresher period for former students and later as a means of utilizing the intersession periods between regular semesters. Other universities would soon recognize the added benefit of garnering additional tuition and enrollment using already paid for resources [2].

Entire university curriculums based on TC course offerings have emerged in growing numbers since the mid-19th century. These accelerated learning environments often offer associate and bachelor degrees in much less time than traditional universities. Two examples include Williams Female College in South Carolina, 1877, and Hiram College in Ohio, 1958 [3]. Modern examples include DeVry University and online schools such as University of Phoenix.

The appeal of time-truncated TC courses cannot be denied especially when viewed in light of the number of universities that offer TC courses in one way or another. According to E.L. Daniel (2000), "data drawn from 424 colleges and universities found that 217 were using accelerated courses and programs" [4]. That was in 1996. The number of universities offering these types of courses has since gone through explosive growth. With widespread use comes an expansion in the number of different applications.

1.3 Extent of Use, Reasons of Use & Different Uses

TC courses, whether offered by large, traditional-time-oriented universities or universities utilizing modular calendars, have been received quite well. Students in general find the courses to be useful for either broadening their studies or helping to fulfill course requirements. Adult students, in particular, appreciate the chance to gain course credit towards a degree in a reduced time frame. The modest beginnings of time-compressed courses have led to an overwhelming number of different modes of course offering including, but not limited to, summer courses, weekend courses, interim courses and modular courses.

The earliest and most popular form of TC course is still the summer course. Popularity increased when colleges and universities began using them as a way to increase enrollment and dilute fixed-costs. Most universities and colleges offer some form of a summer session full of TC courses.

The next big growth area for TC courses is in weekend colleges. Used primarily by otherwise employed adult students as a means to acquire education in an intense format, weekend colleges cater to busy schedules. In 1986, there were already 225 weekend colleges in the US and the number of adult students demanding these colleges continues to rise [5].

Interim courses make use of very short periods of time, e.g., a month, for intense study courses. Their beginnings are rooted in the period of winter break, and spring break in the US. Instructors interested in taking refresher courses during the times they were free from other teaching duties started this new method of offering TC courses.

Modular courses usually make use of short courses such as those used in interim courses. In some situations, three such courses are taken in sequence during each semester. Students cite this as advantageous since each course can be focused on separately and the continuity of course content helps connections to form [5].

1.4 Overview of Thesis

This thesis roughly mimics the author's journey toward an understanding of best practice in TC-STEM course pedagogy. While a significant amount of research has been done on TC courses and STEM course pedagogy, the cross-section is somewhat smaller. As a study of best practice in a TC-STEM course, the thesis will draw connections from various aspects of literature and bring them together into a coherent framework applied to two separate TC-STEM courses taught in the summer 2010 semester.

The thesis begins with an attempt to understand current and past theories of learning through a wide sweeping literature review. The literature review then narrows to focus on STEM courses and current and past theories of pedagogy. Much research, for STEM courses, suggests that traditional methods of teaching are less successful than methods that include active learning, such as scaffolding models. A detailed analysis of this data and the pedagogies that involve active learning constitutes the second part of the literature review. The review wraps up with current research that focuses on TC pedagogy and TC-STEM course methods and research.

To begin a detailed investigation into best practice in TC-STEM pedagogy, the author found it extremely helpful to speak with both experienced faculty and experienced students. Chapter 3 examines a series of surveys conducted at a number of universities, and some informal interviews with both faculty and staff. Chapter 4 parallels detailed examples derived from both literature's suggestion and data gathered from faculty with an actual implementation of the ideas summarized in the preceding chapters and the qualitative and quasi-quantitative results during two separate introductory physics TC-STEM courses.

Chapter 4 of this thesis concludes with a discussion of TC-STEM areas that are in need of further research. Please note that many of the sources and examples pertain to physics courses but can be generalized to include all STEM groups.

Chapter 2: Literature Review

2.1 How we learn and how we teach

Research from most sources seems to indicate that best-practice pedagogy for teaching STEM courses in a TC format involves using active teaching and peer-based instructional methods founded on constructivist theories of the late 20th century. To appreciate the reasoning behind these methods, a few words from past literature describing the theoretical understanding of knowledge acquisition proves useful. Beginning with early classical theories of learning based on philosophy and ending with modern theories founded on psychological undertakings, the learner has progressed from being viewed as an entity that is given or shown knowledge to a person who is fully involved in the actual creation (or construction) of knowledge.

2.2 Theories of Learning

2.2.1 Classical Theories

Classical theories of learning date back to at least the ancient Greeks, and Plato's theory of the student as a "recaller" of innate knowledge. Plato's belief was that, "Knowledge …is in place at the time of birth…learning was a process of recalling what the soul had already seen and absorbed" [6]. In this way, knowledge is neither created nor destroyed, only remembered or forgotten. Of course, a main problem with this philosophy is it gives no way to create new knowledge, nor does it examine the origin of knowledge.

Another early theory of learning and knowledge comes from John Locke. "Locke could not accept that knowledge was innate; in his view the infant came into the world with a mind that was completely devoid of content—it was like an 'empty cabinet,' a 'blank tablet,' or a 'tabula rasa' "[6]. To Locke, the child comes with the bare minimum in "start-up programs," and acquires all that he/she knows through assimilation of tiny pieces of knowledge that are presented to the mind via experience and assembled to create the deep and complex ideas of adulthood.

Although somewhat different in their explanation, Locke, Plato and an overwhelming number of physics and natural science teachers adopt a view that learning is a passive experience for the learner. The learner learns through events (experience or lectures or lessons) that happen to him/her, and not events in which they participate actively. In other words, they *acquire* knowledge rather than *create* knowledge. It was not until Darwin's theory of evolution was proposed in 1859 that humans were viewed as animals, and knowledge began to be viewed as something that the being actively engaged in creating [6].

2.2.2 Behaviorism

Theorists such as Pavlov, Thorndike and Skinner experimented with conditioning and behaviorism. When applied to humans, behaviorism resembles Locke’s view, with his tiny atoms of knowledge replaced by units of behavior. Through reward and punishment, animals (including humans) are “taught” to behave in a certain way. The mind of the student gains knowledge through behavior modification, and is conditioned to engage in certain activities that resemble learned behaviors [6].

2.2.3 Gestalt and Dewey

Gestalt theorists would argue that the inherent meaning in activities is lost when broken down into the small (meaningless) pieces required by conditioning and Locke. “The very word Gestalt means ‘organization’ or ‘configuration,’ the point being that we experience the world in meaningful patterns or organized wholes” [6]. Indeed, the solution to a problem comes after all aspects of the problem and proposed solution are examined in a learner’s head. As prominent gestalt theorist Wolfgang Köhler described, the learner learns by “mentally manipulating these meaningful elements until suddenly a mental connection is made” [6]. This organized handling of the elements of a problem leading to a solution is the essence of knowledge creation.

John Dewey would take the idea of knowledge creation by way of problem solving one step further and argue that the effort expended on solving a problem is what makes the information dear to the learner and stores it in memory in a dynamic way. There is no denial that information can be transferred from teacher to learner, but as Phillips and Soltis quoting Dewey put it, “information severed from thoughtful action is dead, a mind crushing load.” True thinking begins with solving problems, sorting information and making connections [6].

2.2.4 Constructivism, Cognition and Piaget

Behaviorism gave way to constructivism in the early 20th century with Piaget's theory of the development of cognitive structures. Through actively participating in the world around them, children create knowledge of how the world works. They interact with objects and people, later incorporating language as a means of experiencing the world. Speaking of Piaget, Phillips and Soltis (2004) summarize,

> At any stage of his or her development, the young learner will be interacting with the environment…If the experience is one that has been engaged in many times before…the experience will be assimilated in terms of the present structures…Most likely, because the learner is still learning, his or her structures will not be able to completely handle some new experience…At some point there will be a loss of equilibrium and some change (most likely an addition) will be made to a cognitive structure in an attempt to accommodate the novel aspects of the experience [6].

It is thus through this process of assimilation and accommodation that the learner actively takes part in the learning process. Notice too, the importance that this places on the previous cache of knowledge possessed by the learner. Novel experience is compared to previous knowledge banks and analyzed. It is found to either be in agreement with or contrast to. This then places the burden of understanding this new bit of information in the hands of the learner, who must find a way to accommodate this new experience. Since the fit is almost never perfect, learners are continually transforming their understanding.

2.2.5 Lev Vygotsky and the Lone Investigator

Theorist Lev Vygotsky would take Piaget's constructivist learning process one step further, and include social aspects of the learning experience. Whereas Piaget's theory of learning is an individualistic approach (i.e., the learner is the sole creator of knowledge, and the learning takes place in the individual's mind), Vygotsky insisted that learning was a more social feat. The fact that learning takes place primarily based on language interactions shows that at least some aspect of learning must be accounted for socially.

Vygotsky often used learning a second language as an example of social constructivism. At home, bilingual learning is engaged in by repetition and active involvement by the student. To Vygotsky, the learning was spontaneous as opposed to the learning that occurs in school. Speaking of scientific concept learning, Vygotsky is quoted by Panofsky, John-Steiner and Blackwell (1990) as saying,

> The learning of scientific concepts or a second language in school both rely on a previously developed set of word meanings originating from the child's everyday experiences…the development of scientific concepts both depends and builds upon an already existing set of everyday concepts [7].

These previous ideas that a student acquires are the basis of conceptual development. The ideas are acquired in a social setting with either family or friends, and thus find acceptance by the student as the socially normal way of understanding a physical phenomenon. "He (Vygotsky) viewed the earlier knowledge as a more inductively based process of generalization and abstraction that becomes linked with a more deductively explored, systematic conceptual framework" [7].

2.3 STEM Course Pedagogy Based on these Learning Theories

2.3.1 Pedagogy Based on Classical Theory: Traditional Methods

Instead of being created and modified by people trained in the area of education, all too often, physics classes and curricula are designed by physicists, who naturally assume that students in their courses learn much the same way they did. The traditional instruction in natural sciences education is the preferred method of engagement, treating each student like a sponge waiting eagerly to absorb all that the professor has to say. Lillian Christie McDermott, recipient of the prestigious Robert A. Millikan Lecture Award, states in her acceptance address (1991),

> At the college level, the match between instructor and curriculum has always been extremely good. For the most part, the curriculum has been designed by faculty who think of students as very much like themselves. The traditional introductory physics course worked for them as it still does for many physics majors, typically about 1 out of every 30 students in the class…However, there is considerable evidence that the curriculum is not matched to many students in the introductory course [8].

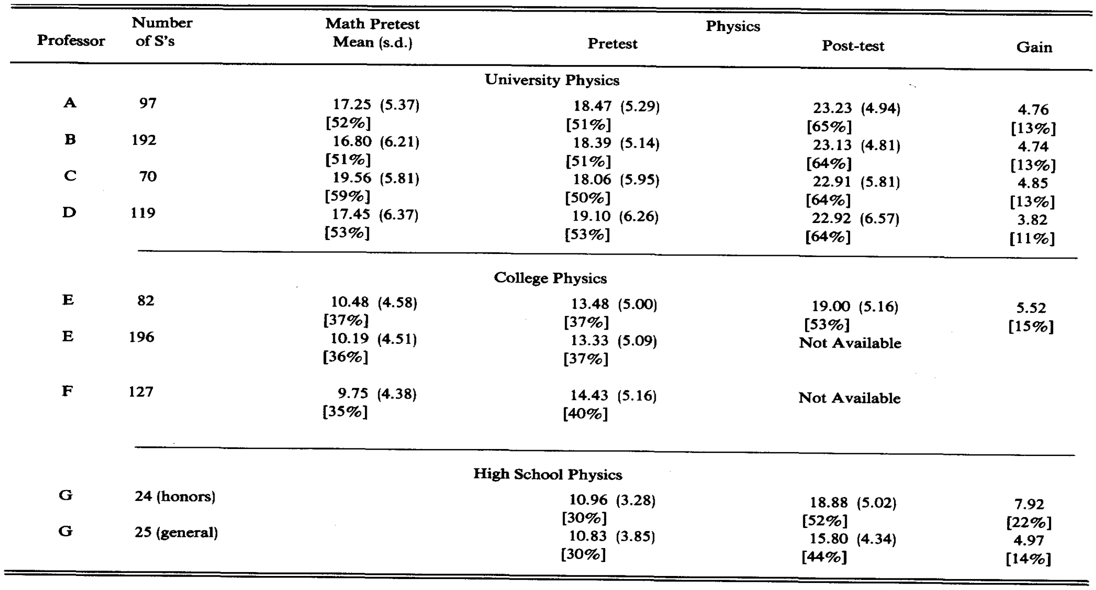
In her lecture, she continues to explain how this mismatch is not due to any malcontent, but rather has to do with what teachers of physics see as important. “A major part of the appeal of physics to a physicist is the generalization and synthesis about the natural world that an understanding of the subject makes possible” [8]. The trouble is that this deep understanding comes only after years of intense study and meditation.

While simply trying to demonstrate this revelation to the student directly, McDermott concludes that “generalizations are often fully formulated…Very little inductive thinking is involved; the reasoning is almost entirely deductive; the student is not actively engaged in the process of abstraction and generalization” [8]. But it is this process that is the point of physics education. Most students are not enrolled in a physics course because of a desire to become a physicist. Most are from various other science and engineering fields, and it is the job of the physics teacher to impart the true beauty of physics onto their students; the generalizing and reasoning capabilities that can be gained through an education in physics are immensely more useful than a memory bank of equations. This true essence of physics is not something that can be shown to a person, so perhaps traditional lecture methods are misplaced in their efforts to teach it.

2.3.2 Incorporating the Initial Knowledge State of the Science Student

In their landmark paper, “The initial knowledge state of college physics students,” Ibrahim Abou Halloun and David Hestenes (1985) set out to prove that “conventional instruction induces only a small change [9]” in the previously held beliefs about physical processes. After developing the benchmark physics diagnostic test, known as the Halloun and Hestenes Mechanics Diagnostic Test (H&H MDT), they conducted a series of tests on 1500 students (80% engineering) in the Arizona State University’s introductory college physics courses. Using a pretest as an indictor of the initial knowledge state and a post-test as an indictor of knowledge state after a semester of traditional education, they drew two important conclusions.

Halloun and Hestenes used the pre-test to examine the initial knowledge base of the students and its effect on knowledge gain. The results are summarized in Table I [9]. With a maximum test score of 36, it can be seen that the student averages are about 50%. What is even more striking is that, after a semester of traditional education and regardless of the professor, all university and college students have knowledge gains of less than 15%.



Professor	Number of S's	Math Pretest Mean (s.d.)	Physics Pretest	 Post-test	 Gain
			University Physics		
A	97	17.25 (5.37) [52%]	18.47 (5.29) [51%]	23.23 (4.94) [65%]	4.76 [13%]
B	192	16.80 (6.21) [51%]	18.39 (5.14) [51%]	23.13 (4.81) [64%]	4.74 [13%]
C	70	19.56 (5.81) [59%]	18.06 (5.95) [50%]	22.91 (5.81) [64%]	4.85 [13%]
D	119	17.45 (6.37) [53%]	19.10 (6.26) [53%]	22.92 (6.57) [64%]	3.82 [11%]
			College Physics		
E	82	10.48 (4.58) [37%]	13.48 (5.00) [37%]	19.00 (5.16) [53%]	5.52 [15%]
E	196	10.19 (4.51) [36%]	13.33 (5.09) [37%]	Not Available	
F	127	9.75 (4.38) [35%]	14.43 (5.16) [40%]	Not Available	
			High School Physics		
G	24 (honors)		10.96 (3.28) [30%]	18.88 (5.02) [52%]	7.92 [22%]
G	25 (general)		10.83 (3.85) [30%]	15.80 (4.34) [44%]	4.97 [14%]

Table 1 – Average Diagnostic Test Results by Course and Professor. Maximum scores: 36, for the physics diagnostic test; 33, for the mathematics diagnostic test including five calculus items which were omitted in College Physics. Source: Halloun, I. A. & Hestenes, D. (1985) The Initial Knowledge State of College Physics Students. American Journal of Physics, 53, p. 1045

Halloun and Hestenes go further, and determine a correlation between initial knowledge state and gain in physics knowledge. Defining their Competence Index (CI) as a measure of the initial knowledge state of the student, they conclude, "With probability greater than 0.60 (60%) in the large student population we have studied, high competence students were likely to receive an A or B…Clearly, low competence students can be expected to have great difficulties with college physics" [9]. The initial knowledge state of the student cannot be ignored, but must be included in a teaching strategy. It is also interesting to note that the differences in teaching style of the four professors had little effect on the students even though they varied greatly within the confines of traditional instruction, from a book-following style to an approach focusing on problem solving examples.

After administering a post-test, Halloun and Hestenes (1985) made the following conclusion:

> Conventional instruction produces comparatively small improvements in the basic knowledge. The implications of failure on the part of conventional instruction could hardly be more serious, for we are not talking about a few isolated facts the students failed to pickup…it means that alternative misconceptions about mechanics are firmly in place…the primary objective of introductory physics instruction should be to facilitate a transformation in the student's mode of thinking from his initial common sense knowledge state to final Newtonian knowledge state of a physicist [9].

Their conclusions are not unique and point out serious problems in the higher educational system's method of instructing students in the natural sciences. Further research began by examining how knowledge is gained, and how best to facilitate learning.

2.3.3 Constructivist Pedagogy: Learning how to Learn

Physics teachers have begun investigating the benefit of examining student's prior knowledge as a factor in the teacher's chosen pedagogy. After examining the correlation between previous knowledge and future learning, Halloun and Hestenes (1985) said,

> The instructor cannot take common sense misconceptions into account without knowing what they are and how they can be changed…. The full value of such insights can be realized only when they are incorporated into a program of systematic pedagogical research aimed at the development of a practical instruction theory [9].

Halloun and Hestenes therefore conclude that more needs to be done in the way of understanding the student's way of learning and previous knowledge base. Later authors would go further and submit that much must also be done to teach students how to learn. Once again, the findings suggest that it is important to use the students' understanding of how physics is learned as a starting point in pedagogical reform. "Students' epistemological beliefs—their views about the nature of knowledge and learning—affect their mindset, metacognitive practices, and study habits in a physics course" [10].

It seems that recent research in this area places the student at the center of learning. Not only are students to be actively involved in learning, their understanding of how knowledge is acquired is equally important. Students entering a physics class prepared to memorize formulae will do just that, when the most important aspect, a conceptual understanding of the material eludes them. In breaking with this cycle, May and Ektina (2002), conclude

> Students should develop self-reflection skills and appropriate views about knowledge and learning, both for their own sake and because these skills and views may be related to improvements in conceptual understanding. We found that students with high conceptual gains tend to show reflection on learning that is more articulate and epistemologically sophisticated than students with lower conceptual gains [11].

Involving students in the learning process allows them to participate, actively, in the creation and retention of knowledge. Further, it conveys to them the importance placed on them to not only memorize and regurgitate what is shown to them, but to embrace the creation of that knowledge as part of the learning experience, e.g., applying the scientific method results in the creation of scientific law and how that law is discovered.

In retrospect, it seems nearly impossible to teach physics in a coherent manner, when the student is convinced that no such coherence exists. Elby (2001) continues, "We can reasonably infer that a sophisticated epistemological stance supports productive study habits and metacognitive practices. For instance, a student who sees physics knowledge as a coherent web of ideas has reason to ‘switch on’ the metacognitive practice of monitoring one’s understanding for consistency” [10].

Research in teaching methods goes beyond changing student views about knowledge gain. By employing the ideas about the way students learn in social constructivism, new methods of instruction have evolved that demand the learner to be actively engaged in the knowledge creation process. Students are not viewed as blank slates in this paradigm, but as knowledge makers. The knowledge is then constructed in a similar manner to the misconceptions - through experiment, discussion and repetition. In these models, the teacher takes on the role of a mentor or a facilitator and guides discussion with questions and through dialogue instead of through a monologue.

2.4 Active Learning in STEM Courses

2.4.1 Problem-Based Learning

Collectively, frameworks of education in which the student's own knowledge construction process is paramount and the teacher is a guide are known as "scaffolding models." Although for reasons that will become more compelling, they have also been known as "minimally-guided" referring to the professor's reduced role from direct lecturer to learning conductor. One such approach is called Problem-Based Learning or PBL. Hmelo-Silver, Duncan & Chinn (2007) explain,

> In PBL, students learn content, strategies, and self-directed learning skills through collaboratively solving problems, reflecting on their experiences, and engaging in self-directed inquiry…PBL often uses text-based resources for both the problem data and self-directed learning [12].

PBL begins with a unifying problem that learning is built around. Students work with their peers and engage in debates to communicate their ideas and solutions. The central problem guides while an instructor plays the part of a scaffold with just-in-time instruction and help.

2.4.2 Inquiry Learning

Another similar model is called Inquiry Learning (IL). Hmelo-Silver et al. (2007) explain

> In IL, students learn content as well as discipline-specific reasoning skills and practices by collaboratively engaging in investigations…IL has its origins in the practices of scientific inquiry and places a heavy emphasis on posing questions, gathering and analyzing data, and constructing evidence based arguments [12].

In the IL model, which is well suited for physics and natural science education, learning takes place in much the same way that researchers learn about their own field. Questions are asked, peers are collaborated with, and arguments are based on findings, data and scientific evidence. In the classroom, the teacher is present almost as a lifeline, when students need help.

Hmelo-Silver et al. (2007) inform that this type of teaching promotes many of the qualities sought for in a university graduate including written and oral skills, concept reasoning, strategizing and self-instruction. Because the knowledge is created by the user it takes hold just as firmly as previously held misconceptions. "Scaffolding not only guides learners through the complexities of the task, it may also problematize important aspects of the students' work in order to force them to engage with key disciplinary frameworks and strategies" [12]. This strategy lends itself nicely to science environments, where the method of learning about the natural world is just as important as the laws that are learned. Immersing students in an environment that enables, and calls to them to think like a scientist will reaffirm the reasons for and limitations of scientific results.

2.4.3 Active Learning in the STEM Classroom

All of these methods have enjoyed great success in research interventions to educate physics and STEM students. Natural science educators have begun adopting the ideas of scaffolding education in their class room. In their paper, "Experimental learning at the university level: A US case study," M. Garvin and R. Ramsier (2003) explain that the lecture based teaching methods not only don't educate students properly, but also rob them of the true nature of physics education. Further, as was pointed out earlier, it is important to understand the students' input in their learning effort. Having the ability to really understand what is being taught, and at the same time endearing it to one’s self is quite a success story in terms of learning a classically opaque subject [13].

In their model, Garvin and Ramsier (2003) claim that the use of “broad-based objectives and goals, tailored to individuals, allows students to take ownership of projects and activities and therefore of their learning” [13]. The semester culminates with a class wide project that incorporates all that the students have learned. Hands-on activities and field trips add to the “real-world experience.” The students take on the class almost as a job: “They are in some sense teachers, colleagues and students simultaneously. The professor is a facilitator, mentor and guide” [13].

Learning takes place through group problem solving activities and presentations of solutions followed by discussion. Homework is also based on group work. Mini-lectures present some of the more difficult material or act as another resource tool for a problem-solving activity. Garvin and Ramsier (2003) agree that this type of pedagogy is resource intensive, and logistically demanding. They experimented with their method and had qualitatively positive results on classes of about 35 students. Most physics departments will argue then that traditional methods are the only possibility in classes with sizes in the hundreds. Research involving the use of technology and teaching assistants to “shrink” the classroom has been undertaken in this area, with some degree of success [13]. One example is elaborated on below.

2.4.4 Peer Instruction

Eric Mazur is a physics professor at Harvard University, and is a pioneer in the field of active learning in physics. His method entitled Peer Instruction (PI) (1997) was revolutionary in that it broke with traditional methods of lecture and favored a pedagogy that resembled the discussions found in social science classrooms. Class time is spent with a series of mini-lectures each punctuated by a ConcepTest, which is a concept based question asked of the students. Students are given time to solve the problem and then discuss it with their neighbor. They then report their answers to the professor either by show of hands, holding up letter answers to multiple choice questions, or handheld computer (clickers). The professor then engages the students in a question and answer session that discusses the correct answer and any confusion. It can thus be seen how Mazur's method can be readily widened to classrooms of all sizes.

PI also encourages students to read prior to class, since ConcepTests will be based on the reading as much as on the mini-lecture given before hand. Since the reading becomes relevant and necessary for participation in class, students begin to appreciate the book as a learning tool: "The convince-your-neighbor discussions break the unavoidable monotony of passive lecturing, and, more important, the students do not merely assimilate the material presented to them; they must think for themselves and put their thoughts into words" [14].

2.5 Success of Constructivist Pedagogy in the Physics Classroom

The success of active learning methods cannot be trivialized. Hmelo-Silver et al. (2007) report that GenScope, part of an IL scheme, has met with great success [12]. GenScope is an interactive, computer environment in which students can genetics by interacting with organisms in a multitude of ways from DNA to cells, even entire simulated populations. The students can then see how the different aspects of inheritance affect the characteristics of the population. Hickey et al. (1999) found that 381 students in 21 GenScope classrooms 'showed significantly larger gains from pre-test to post-test than the 107 students in 6 comparison classrooms [15].'

On PBL, Hmelo-Silver et al. (2007) also show that the much questioned ability to generalize and elaborate is indeed acquired in PBL,

> The PBL students did indeed transfer the hypothesis-driven reasoning strategy they were taught to new problems whereas students in a traditional curriculum did not use this reasoning strategy [12].

The effect of encouraging students to participate in the formulation and solution of problems enables them to determine the aspects of a situation that can be ignored and those that are important. This is exactly what scientists do and so it is no wonder that using this as a teaching method encourages the critical problem solving around which science classes are centered.

In physics, the success rate is astounding. Mazur's PI uses the Force Concept Inventory (FCI) Test and the Mechanics Baseline (MB) Test, both very popular, to evaluate his teaching method. While teaching conventionally in 1990, Mazur's students received a gain of 8% on the FCI (somewhat higher that the national average of 5%) and a MB grade of 67%. After his introduction of PI, the gain on the FCI had risen to 21% and the MB to 76%! Further, as an aside he gave the same final exam that he had given in 1985 (traditionally taught) to his newly taught class of 1991 (Peer Instruction taught). The average rose from 62.7% to a 69.4% with a much smaller standard deviation [14].

In a 6000 student survey, Richard Hake (1997) reports that the interactive learning used at Indiana University, is overwhelmingly successful. By employing the H&H MDT, discussed earlier, both as a pre-test and post-test, he made the following conclusions (<g> is the fraction of the maximum possible gain realized):

> Fourteen ‘‘traditional’’ (T) courses (n=2084) which made little or no use of interactive-engagement (IE) methods achieved an average gain $<g>_{Tave}=0.23\pm0.04$ (std dev). In sharp contrast, 48 courses (n=4458) which made substantial use of IE methods achieved an average gain $<g>_{IEave}=0.48\pm0.14$ (std dev), almost two standard deviations of $<g>_{IE\text{-}ave}$ above that of the traditional courses [16].

The results are not unique to the United States. At the University of New Zealand, Veronica Cahyadi (2004) conducted a study in which she compared students taught identical material either traditionally or with lectures based on constructivist ideas. Besides receiving lectures and problem-solving explanations, students in the experimental classes took daily reading quizzes, watched in-class demonstrations, conducted peer discussion and were guided to complete ALPS (Active Learning Problem Sets) [17].

The results were that the two control classes demonstrated a fractional gain <g> (as described earlier except this time on the FCI instead of H&H MDT) of 0.3 and 0.45, when the traditionally taught classes averaged gains of 0.1. It is interesting to note that in a traditionally taught class where the professor taught exactly from the exam, gains were still only 0.5 [17]!

The traditional methods of physics education, although logical and long standing, have not led to the learning goals desired in students who have mastery of the subject. Further, the one-to-many teaching style of lecture/lab/exam only encourages the student to view physics as a mysterious subject that is only understandable by a small subset of academia. Passively accepting physics ideas that are spoon fed by lectures simply does not work, when misconceptions are firmly in place backed by years of solidifying experience and peer consensus. The student is so wedded to these incorrect ideas that simply telling them that they are wrong can't possibly work. New experiences need to be engaged in first hand, and new understandings need to be created in the same manner as the incorrect ones were created in the first place.

The evidence in favor of active learning is undeniable. Relating to Piaget's ideas Hmelo-Silver et al. (2007) state, "All learning involves knowledge construction in one form or another; it is therefore a constructivist process" [12]. Constructivist theory places the responsibility of learning squarely on students. Since the evidence points out that the teacher involved has little to do with knowledge acquisition, it suggests that the method of teaching is more important. In the active learning pedagogies analyzed above, the student is encouraged to view learning as a process of inquiry and discovery, much as it was for physics majors.

Through accommodation and assimilation, the student begins to correct misconceptions of physical phenomena. The teacher becomes a facilitator, and so the student begins to create his/her own knowledge in a manner consistent with the experiences that led to the misconceptions in the first place. By actively engaging in the problem solving process and corroborating with peers, the student quickly builds confidence in himself/herself. This newfound confidence leads to the motivation necessary to encourage the student to continue learning and participating.

Chapter 3: Concerns about Time-Compressed Courses

3.1 Concerning General Concerns

Many of the troubled views of TC courses arise from the prejudices people carry with them about non-traditional universities, such as University of Phoenix and DeVry University. These universities typically have very open admission standards and primarily use TC courses during their summer and regular sessions as a means to reduce time-to-degree [18]. Due to the accelerated timeframe that these universities use for their course format, they are derogatively referred to as "McEducation" or "Drive-Thru U" [19].

Kretovics, Crowe and Hyun (2005) found that more recently, this misunderstanding has slowly eroded to the point where students view the TC summer session as an opportunity to accelerate their graduation date, enrich their elective course repertoire and alleviate course overload during the traditional fall and spring semesters. Some schools even include TC summer courses as part of their regular curriculum [20].

In a study interviewing 114 students in a variety of disciplines at Australia's Swinburne University, Nicolette Lee and Briony Horsfall found that overall, students reported positive experiences in TC courses. Although both faculty and students initially raised concerns about the TC courses in terms of workload, and timing, an "increased sense of community with and responsibility to their peers, frequency of feedback, and the ability to immerse themselves in a single topic led to benefits that were characteristic of TC courses [21].

Scott (1991) also determined that if courses were presented using active learning techniques and peer collaboration, they led to an experience that facilitated focused and uninterrupted learning experiences…a more memorable learning experience compared to traditional class." She also points out that "the student evaluations overwhelmingly favored the intensive course over the traditional format" especially in the sciences. To further determine the techniques that led to these "memorable learning experiences," it will be helpful to examine the concerns and reservations of experienced faculty and the experiences of students who partook in a TC course [5].

3.2 Faculty Concerns

Professors' viewpoints on TC summer courses have also changed. In light of evidence demonstrating the legitimacy of this teaching format, professorial opinions have shifted toward viewing this time as an opportunity rather than a burden [22]. This is not to say that all fear and doubt have dissipated. Instructors still harbor many concerns over the legitimacy, rigor and success of trying to condense a 16-week course into an 8-week, or 6-week, or 4-week course.

As an instructor beginning a TC course in sophomore-level physics, I had to agree that the task seemed overwhelming and, frankly, almost impossible. At first glance, it appears that the deck is stacked against the learner. In the sciences, for example, retention rates, success rates and grade levels during a regular-schedule, semester-long, traditional physics course are already appallingly low [9]. How could anybody expect even the same level of success when the time spent on material in the classroom setting is cut in half or, even, quartered? Furthermore, summer is often a time for students to engage in more extracurricular activities such as employment and family obligations, which cut into their available outside study time [23].

The time limitation imposed during a TC summer course, influences other aspects of the course, as well. In an effort to strain out any superfluous content, many professors agree with Scott's (1996) findings that our primary concern, after lack of time, is the sacrifice of the breadth of the course and the lack of rigor during in-class deductive reasoning [24]. Daniel (2000) further points out that with such a limited amount of time both in class and out of class, our concerns also include lack of time to actually reflect and absorb the material that we do get to present. We are thus stuck with a course that does not seem to be as useful as a full semester course, cannot possibly cover the same amount of content and does not seem to allow for information up-take [4].

As if this were not enough, our ability to create a robust learning experience for students in TC courses is stymied by the almost complete lack of formal training in the area of teaching such a course. In a study conducted at Kent State University in 2005 by Kretovics, Crowe, and Hyun (2005), nearly 84% of faculty reported receiving almost no training regarding summer teaching. In fact, in the same report, 83% of faculty reported not even receiving mentoring [20]. This lack of assistance is not unique to Kent State University. Tom Phillips (1999) agrees that formal training of any kind in the teaching discipline, including training for summer instructors, is woefully deficient [25].

In the face of all of this skepticism, all of these legitimate concerns and the almost complete lack of university aid, summer course instructors, are still entrusted with teaching in this TC setting. By definition, we must help these students learn. This gets to the heart of this thesis. What do we do? By analyzing available literature, and interviewing faculty and students, it has become apparent that there are many things that can be done.

3.3 Student Concerns

Often when planning a course, consideration of the audience (the students, in this case), is placed behind such concerns as content, available technology and course materials. However, the learner should be our focus. Ultimately, as Craig Swenson (2003) points out:

> The obvious lesson is that teaching formats and structures do not guarantee results. Teaching is neither a necessary nor sufficient condition to ensure that learning occurs [26].

It seems, therefore, imperative that we consider first, the student's expectations for intensive course formats and second, the serviceable attributes of a high-quality TC course. In the case of the latter, many authors agree that a decisive mark of a high-quality learning experience, TC or otherwise, is measurable achievement of learning goals and objectives set forward at a course's commencement [4, 24, 26].

Many assumptions that students of TC courses carry with them on the first day of class are based on ill-conceived presumptions. For example, owing to the fact that students observe the limited amount of time budgeted for the course, they naturally assume that the commitment of time they need to make is likewise limited. Indeed, Wayland, et al. (2000) point out that many students enroll in TC courses because they assume the amount of time commitment will be proportionally lower and that course standards will similarly be lessened [23]. Students may be joining TC summer courses for academic reasons, but still carry with them a belief that summer courses will be more relaxed and less rigid [24].

Some of these notions of loosened standards may be accounted for by the changing demographic in accelerated courses and universities, in general. Daniel (2000) observes:

> Approximately 50% of all college students in the United States are 25 or older, a 50% percent [sic] increase in the past 20 years. In addition, the number of part-time students have also increased significantly [4].

Adult students and part time students often expect that compressed courses will cater to their much busier personal schedule and that the assignments, readings and outside class-time workload will all reflect this consideration. Additionally, Scott (1996) points out that students expect a more relaxed atmosphere surrounding the course, overall and that assignments and assessment will reflect that tone [24]. To verify this conclusion, I conducted an informal survey (e.g., show of hands) in the TC courses that were taught. When asked, "How many people believe that less work will be required in this class because it's a summer course?" nearly every hand went up. I then showed them a very full slide summarizing the large amount of work that would be expected of them, and we all had a good laugh.

Whereas some of the expectations that students bring with them need to be stifled quickly, many are quite in line with what has been demonstrated as effective for intensive (and traditional) courses. At the forefront of the expectations list of students are the expectations placed on the instructor. Study after study has indicated that students believe their success ultimately lies with the instructor. In addition, while Swenson would probably agree that it is not our job to drop nuggets of wisdom into students' heads, students have continuously pointed to many attributes of faculty that create an environment that is conductive to learning.

Scott (2003) details a list of attributes that instructors would do well to note [27]. These are summarized in Table 2.

Characteristic of Professor	**Description**
Enthusiasm	**A passion for both the subject matter and teaching…it's infectious.**
Knowledge and Experience	**A demonstration of a deep understanding of the material and the familiarity that can only come from living it.**
Good Communication	**The ability to take that vast store of knowledge and experience and present it to them clearly at their level of understanding.**
Willingness to Learn from and Consult with Students	**The readiness to stop being the expert and learn with them and from them. To allow for their input on course objectives and expectations.**
Student Orientation	**A demonstration that student learning is the true mark of course success and that we care.**

Table 2 – Desired Attributes of an Instructor. Attributes that students of TC courses listed as most important for a good learning experience. This is a tabular summary of relevant attributes from Scott (2003), [27].

3.4 Need for Changes to Pedagogy, A Student's Perspective

In the same informal survey that I conducted in the summer 2010 TC course (using show of hands), students almost unanimously agreed with the following statements:

- I learn better, when I am involved in the discussion of material.
- I learn better, when activities involve applying knowledge to practical situations.
- I learn better, when we cover less material more deeply.

These conclusions are by no means unique to my class. Many authors have pointed to the need for instructors to change their teaching practices for a TC course. Suggested alternatives and adjustments to the traditional teaching methods include active learning, experiential learning, lectures that involve dialogues instead of monologues, classroom interaction, and PBL to name a few [4, 6, 27, 28].

These interviews become quite interesting when compared to what the literature has to say. Daniel (2000) argues:

> Instructors may need to modify their instructional approaches to maximize students' learning experiences in intensive courses…in order for intensive courses to be a positive academic experience, instructors must employ a variety of teaching methods and establish a comfortable classroom environment [4].

With a wealth of new teaching strategies available, students and instructors have realized that a relationship that mirrors a professional relationship with direct interaction, cooperative problem solving and mutual learning leads to a classroom setting that is most conductive to learning. And Scott (2003) agrees:

> In addition to certain instructor characteristics, students wanted instructors to use what they considered to be effective teaching strategies…Students unanimously identified

> active learning as essential to intensive courses…students wanted to engage the material actively [27].

Often the stigma that lecturing (the sage on the stage) is the best method of teaching is difficult to shake. As Lillian McDermott (1991) points out, it is the way that we, the scientists, learned science but we are only 1 in 30 [8]. The evidence is therefore mounting that simply lecturing may not be as effective as we, the teachers, want it to be. Scott (2003) further points out that, "students advised intensive course instructors to avoid lectures when possible" [27]. It does not get much clearer than that. But this is of course not to say that lectures have no place in the TC classroom. Remember that students want to hear about their instructors' experiences. They like to be shown real cases of knowledge application and see demonstrations. Students should expect these for any course, but due to the intensity of a TC course, students feel that the breakneck speed needs to be balanced with a healthier student-instructor relationship [27]. How will professors respond?

3.5 Faculty Informal Interviews

To gain some perspective on experienced faculty's views of TC-STEM course pedagogy, I conducted informal interviews with faculty members in several departments (including the Pennsylvania State University's Physics Department). The real names have been replaced with pseudonyms. The interviews were conducted either in person (Professor Visus) or through a phone call (Professors Ardent and Visus). I will summarize the results following a brief description of each.

Professor Ardent is devoted to the maintenance of traditional methods of teaching. I would like to note that he has had no formal training in physics education, only a degree in physics itself. A well-versed member of the physics department, he gives primarily PowerPoint based lectures that involve almost no interaction from the audience. During his course, lecture is supplemented by recitations involving group work on a problem set and labs consisting of an experiment recreated by following detailed instructions.

Professor Medio has recently been hired his department after graduating with a degree in experimental physics. He has taken several courses in physics education. He enhances his lectures with demonstrations and works through problems on an overhead projector soliciting the audience for help with each succeeding step. He uses similar labs to Professor Ardent, but recitations are now problem-based group activities (e.g., determine who was at fault during this automobile accident).

Professor Visus believes fully in active learning. He still lectures, but accents his lectures with discussions. He accomplishes this by first memorizing as many student names as possible. His recitations are similar to Professor Medio's recitations in that they are group-work involving a central problem. His labs are radically different though. Instead of recreating an experiment by following detailed instructions, most lab procedures are a brief introduction followed by a question (e.g., can you design an experiment to measure how stiff this spring is?).

When asked whether they would change content when teaching a TC-STEM course, Professors Ardent and Medio remarked that this would mainly involve content trimming, although Professor Ardent felt confident that he could still "squeeze in most of it." Professor Visus commented that breadth would have to be sacrificed if students were to learn anything. When asked whether they would alter assessment techniques or assignments, Professors Ardent and Medio immediately answered no. Professor Ardent further commented that to do so would render the course different from the full-length version and impinge on the department's ability to guarantee that all students had received a similar education. Professor Visus answered that in general no, but the students would be responsible for two written group projects (e.g., explain how an oilrig works using fluid dynamics), in addition to two examinations.

Finally, when asked whether they would alter their teaching methods for a summer short course, Professor Ardent stated emphatically "no, of course not." Professor Medio commented that the smaller class size lends itself to more class participation but was unsure how to implement it. Professor Visus stated that with a smaller class size, learning people's names would be easier and that incorporating people's backgrounds into the discussion would also be included. He further commented that in-class discussions would be easier to begin and as such would be incorporated more fully.

3.6 Faculty Views and Pedagogies – A Survey

When confronted with this enormous list of demands placed on the teacher and not to mention the ever-present time factor, what have instructors determined as the best course of action? In their 2005 study at Kent State University, Kretovics, Crowe and Hyun, presented a survey consisting of 34 questions, a third of which asked about teaching method changes made for TC courses, to 569 faculty members and received 151 replies. The results were:

> 46% (n=63) of the faculty surveyed indicated that they made changes in their syllabus, 33% (n=45) changed reading assignments, 39% (n=55) changed writing assignments, and 40% (n=54) changed projects assigned. Regarding the assessment of students, 31% (n=43) of those responding indicated making changes to their assessment measures. Additionally, 39% (n=55) of the faculty responding indicated they reduced the content of their summer courses [20].

We may not know the exact changes that were made, but what is clear is that many professors recognize the need for adjustments similar to the ones outlined by Scott and Daniel.

What are even more telling are the faculty perceptions of the students taking their summer TC courses. From the same study:

> Faculty believe that they are able to establish rapport with students more quickly in compressed courses (74.4%) and that students are more focused on learning outcomes (64.5%), that students participate more in class discussions (62.3%), that students attend more regularly (69.7%), and that summer school students are academically stronger (46.6%) [20].

It seems to be quite apparent that with some adjustments to content, methodology and assessment, instructors can take the task of summer teaching and spin it into an amazing experience. The literature review has presented a compelling argument for a number of modifications to STEM pedagogy that lead to marked measures of success in both regular and TC-STEM courses. The next chapter addresses specific examples that are suggested as most useful and were implemented in two introductory TC physics courses in the summer of 2010 at the Pennsylvania State University (PSU).

Chapter 4: TC-STEM Best-Practice:

4.1 Literature's Suggestions

Research has indicated that the best way to engage TC-STEM courses is well in line with assuaging student and faculty concerns. Among the best practice techniques thus far established, a pedagogy incorporating an enthusiastic, knowledgeable, experienced faculty member with a student centered active learning environment leads to the most knowledge gain. Among the target areas are, clearly outlined course objectives drawing language from Bloom's Taxonomy, lectures that involve students' active participation, homework assignments with concise grading rubrics, and PBL in the recitation and laboratory portions of the course.

Two studies proved to be invaluable when determining best practice in a TC-STEM course. The first is Patricia A. Scott's (1993) *A Comparative Study of Students' Learning Experiences in Intensive and Semester-Length Courses and of the Attributes of High-Quality Intensive and Semester Course Learning Experiences* [29]. The other is Eileen L. Daniel's (2000) *A Review of Time-Shortened Courses Across Disciplines* [4]. Each article is in good agreement across disciplines, and with previously outlaid active learning techniques as to the attributes of a high-quality TC course.

In her landmark study, Scott (1993) compares the TC course experiences of 29 students and 2 faculty members in a British Literature class and a Sales Methods and Procedures class. By attending *all* class sessions, Scott was to not only to observe, but also participate in the course. She compiled interviews, questionnaires, grades, outlines and any other document distributed in the class. Her findings were extremely useful and will be discussed thoroughly in the rest of this chapter [29].

Daniel (2000) agrees with Scott (1993) in many respects and continues the study to include the education, math, science and computational disciplines. Daniel's study pulls results from over 20 sources together, and addresses both student and faculty concerns, as well as techniques that work well in the intensive TC course format [4].

The key areas addressed by each author became the areas that were actively pursued during the execution of the Physics 213 Fluids and Thermal Physics class and the Physics 214 Wave Motion and Quantum Physics class that I taught. Each class consisted of roughly 35 students from many different backgrounds. They took place during a 4 week period (half the normal allotted time) during the summer session at PSU. The students met twice weekly for lecture discussions (75 minutes each), twice weekly for recitations and once weekly for laboratory practicum. Two homework assignments were due each week, one written and one computer generated problem set. Two exams consisted of 40% of the grade, homework was 30% and laboratory, recitation and class participation were each 10%.

The results for each class were a high B average with only one failing student. Student evaluations rate the class at 4.8 out of 5 with many positive written comments. The quality of the work submitted by the students was exemplary. The subsequent sections present a detailed analysis of those areas that I targeted for adjustment, followed by the implementation, a qualitative discussion of results and areas targeted for further research and engagement.

4.2 Clearly Outlined Objectives

Scott and Daniel both point out that in the TC course, students need an instructor who is quite organized and clearly outlines exactly what is required of the student. According to one of the studies quoted by Daniel, the first key element in a successful TC course is “careful organization by the instructor.” Indeed, Scott agrees that instructors need to communicate effectively while presenting material in an organized fashion. At the same time she found that instructors need to “exercise flexibility in the classroom” and be sensitive to students’ academic and non-academic needs” [29].

To meet these two competing requirements of organization and flexibility, McKeachie *et al.* (2011) recommend laying out the targeted learning outcomes of the course into groups of goals with specific, clear, measureable objectives for each. PBL is an excellent way to take a course objective and relate it to the audience through a real-world problem [28]. Walvoord (2010) further points out that the use of rubrics and test blue prints as a method of clearly outlining which objectives correspond to which assignments and test questions helps students see the organization and relevance of course activities [30].

The objectives for a course not only outline the course, but also constitute an agreement between teacher and learner. As a set of targeted learning outcomes, they provide the aims of every other aspect of the course, including homework, in-class discussions, demonstrations, labs, recitations and, especially, exams. To get the most out of course objectives, it is imperative that the objectives be written in such a way that they are clear and specific, concise and short term and assessable and measurable. The literature is careful to draw a clear distinction between *goals* and *objectives.* Goals are the broad, fuzzy and usually general aims of a course, e.g., “The student will learn the basic concepts of fluids and sound.” Objectives should utilize only action verbs and represent a distinct learning outcome or observable student behavior, e.g., "The student will define a fluid and state several examples and counter examples."

To help construct a set of goals and a set of objectives for a course, a number of resources are available. The author found a good place to start was by creating a teaching goals inventory. The purpose of such an inventory is to better understand the goals, objectives and methods of assessing those targets. Many web resources (e.g., University of Iowa's Teaching Goals Inventory…Online) are available that will ask questions about the course and help direct the instructor toward the types of objectives and goals appropriate to the course.

The Schreyer Institute for Teaching Excellence at PSU provides excellent help for constructing objectives and goals along the lines described above. When constructing objectives, the action verb describing the desired behavior is the most important part of the intended outcome. The verbs used in objective construction were first categorized by Benjamin Bloom and David Krathwohl into three groups called domains of learning: Cognitive, Attitudinal and Psychomotor. Each of these is further divided. The cognitive, for example, is divided into three levels: Recall, Interpretation and Problem-Solving. These categories are then split once more into groups of verbs that specifically target knowledge and comprehension (Recall, level 1), application and analysis (Interpretation, level 2) and synthesis and evaluation (Problem-Solving, level 3) [31, 32].

In the introductory physics courses taught by the author, most objectives fell into the cognitive domain and followed a basic chronological structure of first targeting knowledge and comprehension hierarchies of the recall level, followed by the application and analysis subgroups of the interpretation level and lastly problem-solving through synthesis and evaluation. Please see the Appendix for an example of the goals and objectives used for Physics 213: Fluids and Thermal Physics.

Objectives, although clear and precise, will by no means limit the flexibility of a course. In fact, now that the targeted learning outcomes are clearly defined, the ways in which to teach and to assess have a direction leading to activates that are also targeted and specific. Scott points out that in a TC course, students responded well to having some control over course content and objectives provide a perfect way for the instructor to maintain the learning outcome and allow students to have input on course content [29].

While an objective may be to solve a problem using previously gained understandings, the situation that centers the problem can be tailored to fit the audience. As an example, consider an objective such as “The student will apply the concept of the equation of continuity to situations involving fluid dynamics.” Initially in the course, I distributed index cards that asked for, among other things, one question students would hope to answer by the end of the course (relevant to the proposed course content, of course). Several petroleum engineers responded to this request by asking to learn how an oil well operates. This question provides an excellent opportunity to both tackle the objective and allow students the ability to tailor course content to something relevant to their interests. It is also well in-line with IL and PBL, which enjoy success in both TC and STEM courses by centering on inquiry and real problems much like professional scientists.

4.3 Enthusiasm and Process

Of all the aspects identified by faculty and students as important to success in a TC or STEM course, perhaps the most important was the professor. Scott lists a number of qualities that students state as requirements for a “good learning experience.” Summarizing the qualities listed, students require a teacher who is creative, enthusiastic, knowledgeable and experienced about teaching and the subject being taught. Students also desired a teacher who can communicate effectively at their level and treat them as a colleague [29].

Cultivating each of these aspects takes time and dedication, but there are a few things that can be implemented immediately. One of the fastest ways to begin building professional relationships is to learn a person’s name and the classroom is no exception. Beginning the course by handing out index cards and asking for information and desired outcomes allows students to have some control over the course. This has the effect of giving them ownership over the learning process and makes students feel heard. The index cards also serve as a method to learn more about the target audience including experience and background.

Another method suggested by McKeachie et al, is to allow many opportunities for feedback during the course, and follow through on it [28]. This is also in good line with Scott’s findings that students want “a connection to the teaching and learning process itself” and they want a teacher who is sensitive to their needs [29]. Once again, index cards prove useful in this respect. Asking students to anonymously fill out a mid-course feedback card stating what is working and what is not working is a great way to assess the effectiveness of the process and ameliorate trouble areas in a timely manner [28].

Over the summer, I engaged each of these areas as much as possible. Mid-course feedback helped identify pacing and process issues that enabled a correction to the course in real time before it ended. The introductory index card exercise also proved quite useful. After reviewing the responses, for example, a tally revealed a large number of petroleum engineers and so directed the instructor to spend extra time on fluid dynamics. Finally, learning everybody's name was probably the most important interaction at the beginning of the course. It allowed for easier class discussions, demonstrations and interactions, as well as, fostering a closer student-mentor relationship.

4.4 Active Classroom Discussion and Peer Interaction

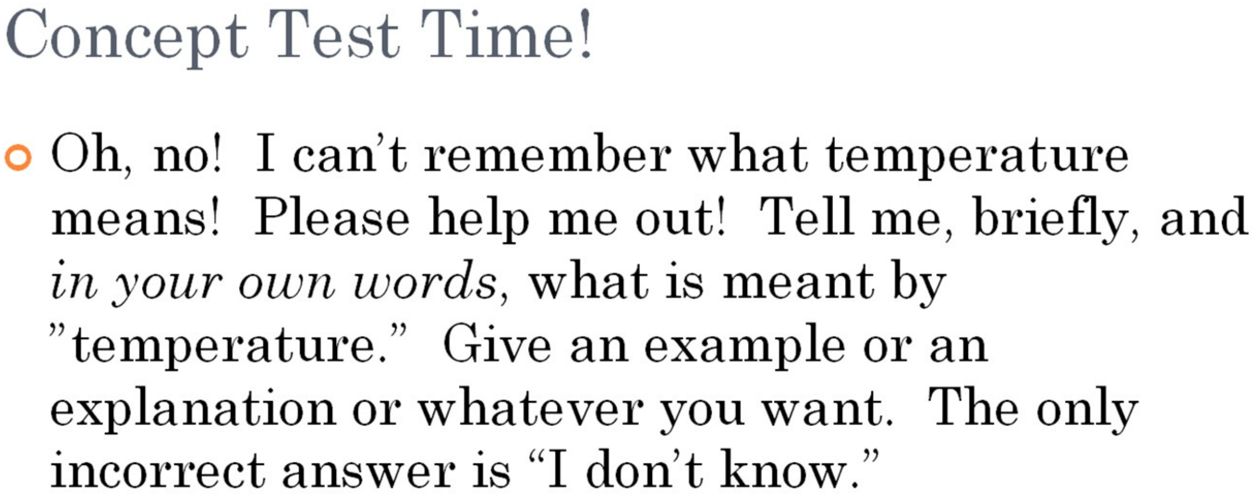
Creating a learning environment where active classroom involvement flourishes and where interaction among peers is copious was outlined in the literature review as some of the most important aspects of success in not only TC and STEM courses, but for courses, in general. In the classroom, introducing these ideas, even marginally, has shown measurable gains. Three basic methods of introducing constructivist methods of active learning include use of Classroom Assessment Techniques (CATs), PI and Experiential & Problem Based Learning.

CATs are an excellent method of getting students involved with problem solving during class time, receiving continuous feedback about students' progress and understanding and giving another opportunity for PI. Some examples of classroom assessment techniques are given in Table 3.

Name of CAT	**Description of CAT**
Concept Test	**Students are given a concept oriented question that is answered individually or in small groups. Answers are discussed and/or collected.**
Minute Paper	**Usually as an opening or closing activity, students are asked to write for a minute or two discussing important points from lecture/reading or asking questions about difficult areas.**
Memory Matrix	**Students fill in the partially-filled columns of data for which labels are given.**
Application Card	**Students write down "real world" applications of a theory or principle that they just learned.**
One-Sentence Summary	**Students summarize a discussion or lecture with one single sentence.**

Table 3 – Sample CATs. A list of some particularly useful CATs for gaining real time feedback from students during lecture discussions and for keeping students actively involved in the classroom discussion

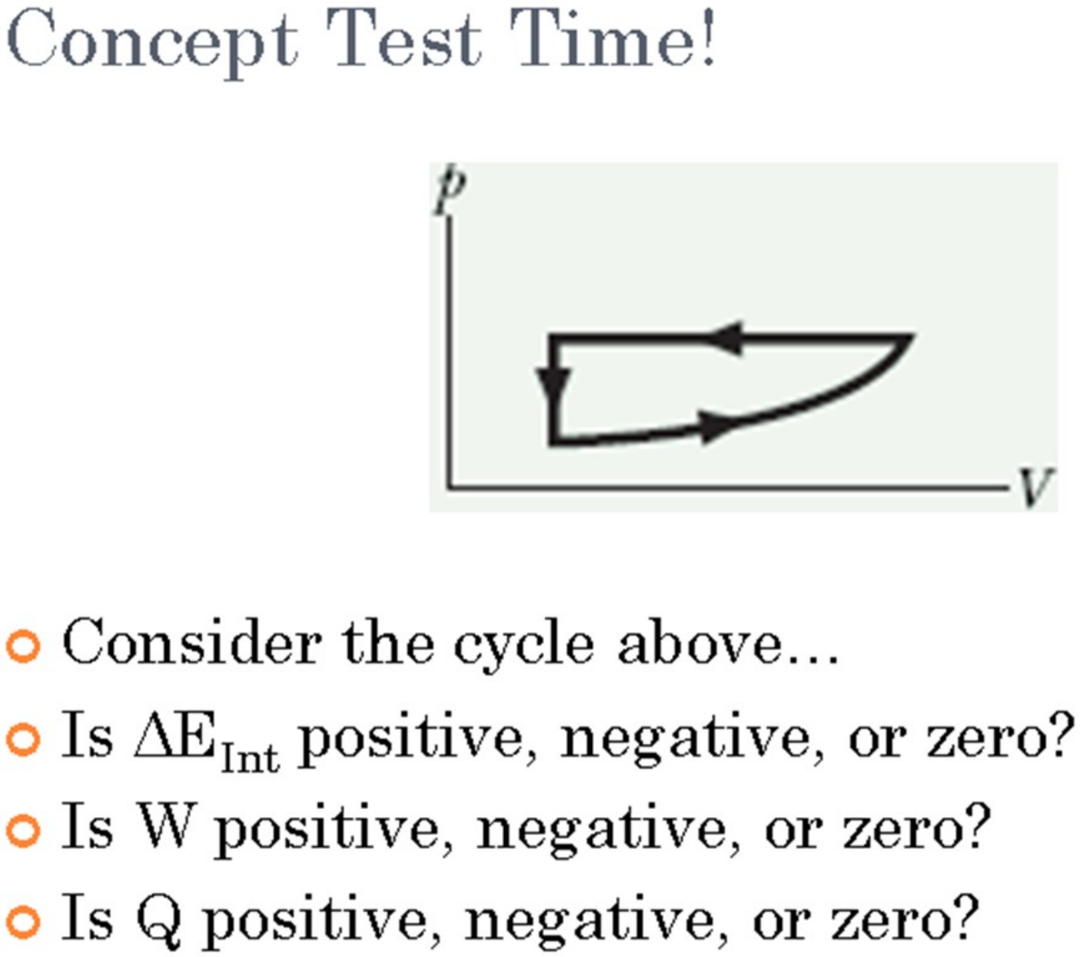
Usually taking the form of a short activity or group discussion, CATs have the added benefit of engaging students in the learning process and delivering feedback to students individually that is decoupled from grades. Two techniques that the author made use of in his introductory physics classes were Concept Tests (another form of "think-pair-share") and memory matrixes, please see Figures 1-3.



Concept Test Time!

- Oh, no! I can't remember what temperature means! Please help me out! Tell me, briefly, and *in your own words*, what is meant by "temperature." Give an example or an explanation or whatever you want. The only incorrect answer is "I don't know."

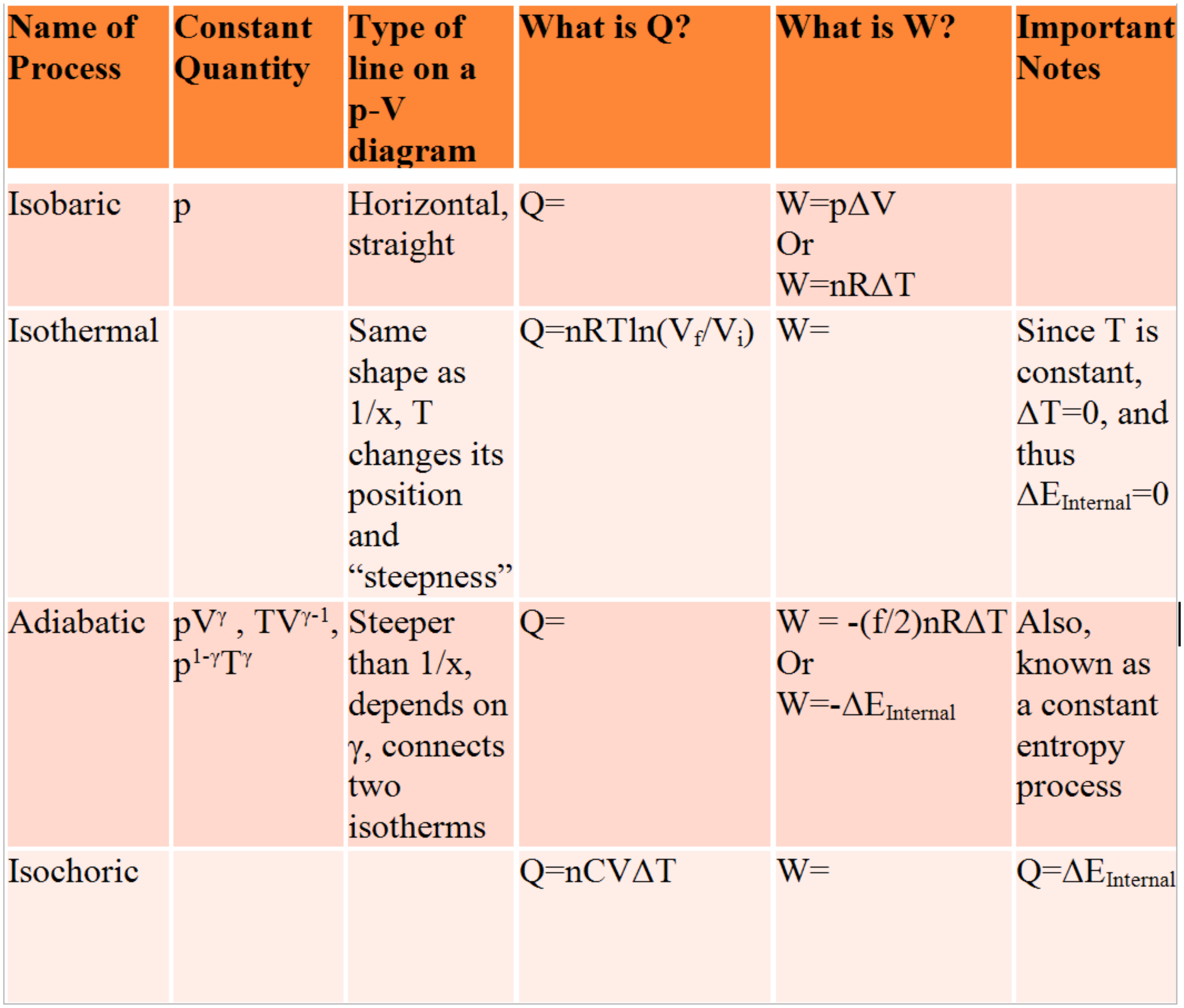
Figure 1 - Temperature Concept Test. This CAT allows for real time feedback on students misconceptions of temperature.



Concept Test Time!

- Consider the cycle above…
- Is ΔE_{Int} positive, negative, or zero?
- Is W positive, negative, or zero?
- Is Q positive, negative, or zero?

Figure 2 - First Law of Thermodynamics Concept Test. This CAT aids in generating a discussion on relevant thermodynamic quantities read off of a p-V graph.



Name of Process	Constant Quantity	Type of line on a p-V diagram	What is Q?	What is W?	Important Notes
Isobaric	p	Horizontal, straight	Q=	$W=p\Delta V$ Or $W=nR\Delta T$	
Isothermal		Same shape as 1/x, T changes its position and "steepness"	$Q=nRT\ln(V_f/V_i)$	W=	Since T is constant, $\Delta T=0$, and thus $\Delta E_{\text{Internal}}=0$
Adiabatic	pV^{γ} , $TV^{\gamma-1}$, $p^{1-\gamma}T^{\gamma}$	Steeper than 1/x, depends on γ, connects two isotherms	Q=	$W = -(f/2)nR\Delta T$ Or $W=-\Delta E_{\text{Internal}}$	Also, known as a constant entropy process
Isochoric			$Q=nCV\Delta T$	W=	$Q=\Delta E_{\text{Internal}}$

Figure 3 - Thermodynamic Quantity Memory Matrix. This CAT has missing information that students fill in during class discussion.

The method of using Concept Tests during classroom discussions varies from source to source, but some common ground exists between the methods. In general, the questions themselves are more conceptual than calculation based. They usually deal with familiar misconceptions (see Figure 1) or situations that can be somewhat challenging conceptually when first encountered (see Figure 2). After the question is asked, students are given a minute or two to think about the question. Sometimes they report their answers at this point and these are discussed. In Mazur's PI, the students now have a chance to discuss ideas with their peers and another class discussion commences [14]. Regardless, the involvement by students in the course progress is greatly enhanced, and the instructor receives real-time feedback on whether concepts are being learned and misconceptions dispelled.

Memory matrixes are another useful CAT. Although they do not necessarily aid in the production of discussions, they are useful in keeping students involved in the class. In one variation (See Figure 3) a partially-filled-in table is distributed and students fill in the missing ideas as the class progresses. This technique is better suited to situations involving large collections of factual information that should be organized for easier comparison.

As discussed in Chapter 2, PI has many benefits in addition to promoting an active learning situation. Peers often carry similar experiences in terms of physical phenomena (e.g., use of computers in the 90s or digital media in the 2000s), use similar colloquial language (e.g., generation gap) and have similar misconceptions when at comparable levels of understanding (e.g., force causes motion or velocity and acceleration are always in the same direction). Ultimately, they will work together on the homework, recitations and laboratories, so their ability to communicate with each other may in some respects be more eloquent than our interactions.

During lecture discussions facilitated by the instructor, many good discussions began by applying concept tests during lecture time. Students commented that working together helped drive home important points and allowed for a more comfortable discussion setting than speaking before the entire class and instructor. I used comments from concept test results to tailor future discussions and course direction to great effect. Student comments gave conclusive evidence that students do enjoy participating in class and require ample opportunity to do so.

4.5 Interactive Lecture Demonstrations

As another method of active classroom learning, Interactive Lecture Demonstrations (ILDs) proved quite useful. Demonstrations during class time are useful for refocusing a class and reminding students about the role of experiment in the creation of our science. However, in an ILD, students can participate in the experiment itself. Students begin by making predictions about an experiment, observe the demonstration of the experiment and then compare predictions and results. For details on ILDs, see Thorton and Sokoloff [33, 34].

As an example of the use of ILDs during the author's introductory physics course, consider the photoelectric effect experiment. In general, the demonstration's purpose is to reveal to students that the energy transferred from light to electrons in a metal occurs in tiny quantized packets called photons, the quantity of which depends only on the color (frequency) of light and not the intensity or duration of exposure. A five-minute description of the apparatus is followed by a 10-minute discussion of the theory. Several questions guide another ten-minute period during which individual students write down predictions (quasi-hypotheses), before discussing their ideas with fellow students. The demonstration follows and a period of discussion commences about pre-recorded predictions and observed phenomena. In the case of the photoelectric effect, a graph of data is created in real time and the characteristics of the graph are discussed in relation to students' predictions. As a final point, Planck's constant is measured and a discussion of the quantization of light begins.

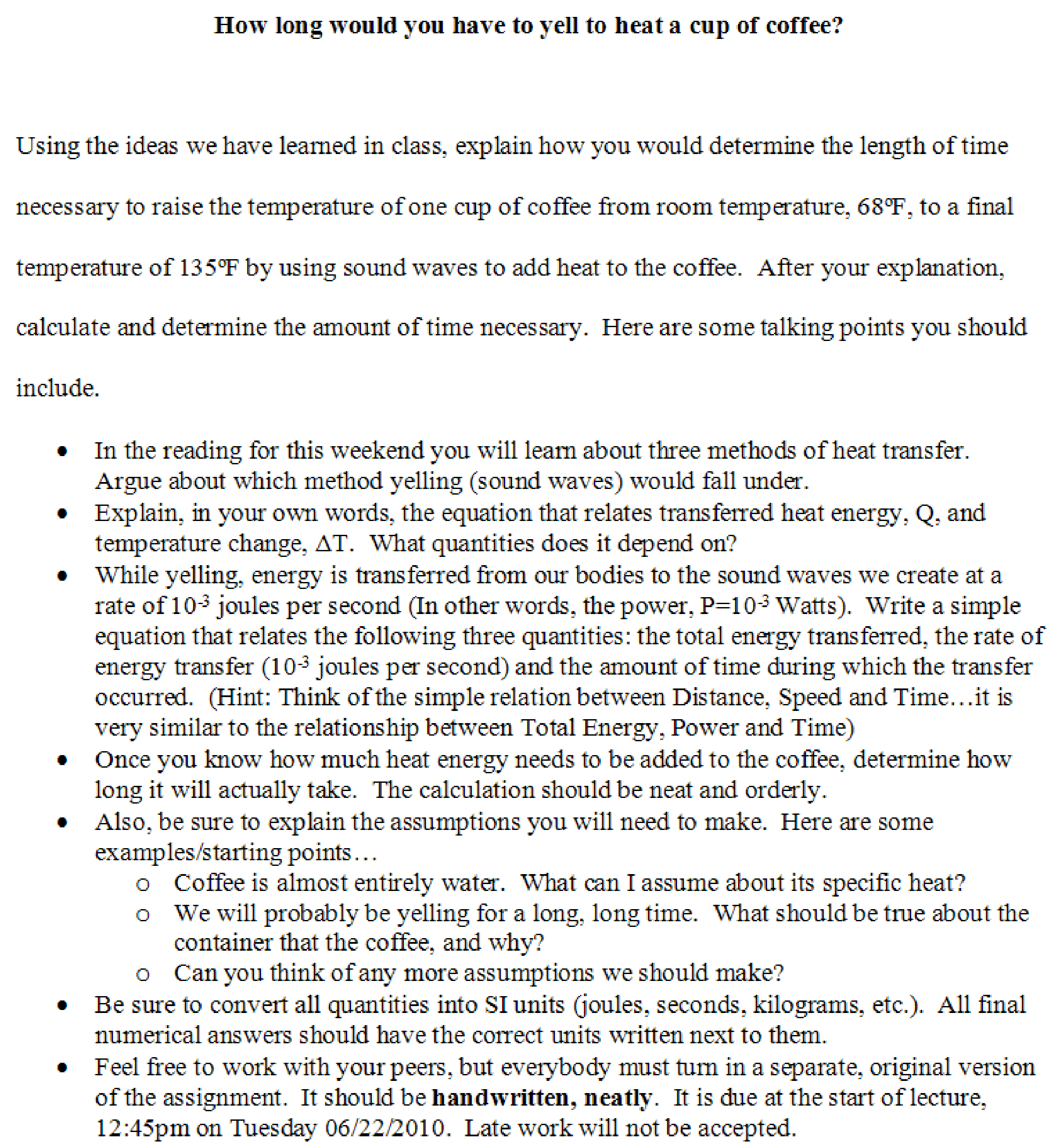
It has recently been reported that similar practices have led to substantial gains in knowledge in the classroom. After compiling ten years of study focusing on the utility of ILDs, Sharma et al (2011) found that measured learning gains were in the 50% range! This is astounding when faced with the reality that learning gains for students not exposed to ILDs was in the 13% range. Their study also showed that incorporating ILDs could be difficult and time-consuming but that students chose ILDs as the best part of the course. Finally, the study concludes that ILDs “led to increased involvement of the class… rapport between the class and the lecturer” and the development of stronger intuition regarding concepts [35]. I observed similar results in both of the TC-STEM courses I taught.

4.6 Problem-Based Learning in Homework, Recitation, Lab

Scott and Daniel point out that good learning experiences involved assignments that allowed students to not only apply their learning, but to do so in a meaningful way. As pointed out in the literature review, PBL is especially useful in a STEM classroom, since abstract ideas and equations can be drawn together by problems from the real-world [4, 27].

Some of the best places to apply PBL are in homework, recitations and laboratories. In recitations, a central problem such as drilling a well for fluid dynamics or explaining how a musical instrument works for wave mechanics, keeps the student focused on a real world problem that is solvable with the new tools they have begun using. The task needs to be challenging but achievable.

The author also found that using humor can be helpful. For a homework assignment, I drew inspiration from a poster I saw in the Society of Physics Students' lounge that simply said, "How long would you have to yell to heat a cup of coffee?" Please see Figure 4. As an assignment, it was perfect for discussing methods of heat transfer, temperature change's relation to heat transferred and the time necessary for heat to be transferred by the method they discussed earlier. Students in general saw the assignment as informative and useful. Several end-of-semester comments agreed that the written homework assignments were well made and the provided rubrics helped by making the strengths and weaknesses of the students clear. From my perspective, the submitted work was well crafted and organized, as well.



How long would you have to yell to heat a cup of coffee?

Using the ideas we have learned in class, explain how you would determine the length of time necessary to raise the temperature of one cup of coffee from room temperature, 68°F, to a final temperature of 135°F by using sound waves to add heat to the coffee. After your explanation, calculate and determine the amount of time necessary. Here are some talking points you should include.

- In the reading for this weekend you will learn about three methods of heat transfer. Argue about which method yelling (sound waves) would fall under.
- Explain, in your own words, the equation that relates transferred heat energy, Q, and temperature change, ΔT. What quantities does it depend on?
- While yelling, energy is transferred from our bodies to the sound waves we create at a rate of 10^{-3} joules per second (In other words, the power, $P=10^{-3}$ Watts). Write a simple equation that relates the following three quantities: the total energy transferred, the rate of energy transfer (10^{-3} joules per second) and the amount of time during which the transfer occurred. (Hint: Think of the simple relation between Distance, Speed and Time…it is very similar to the relationship between Total Energy, Power and Time)
- Once you know how much heat energy needs to be added to the coffee, determine how long it will actually take. The calculation should be neat and orderly.
- Also, be sure to explain the assumptions you will need to make. Here are some examples/starting points…
    - Coffee is almost entirely water. What can I assume about its specific heat?
    - We will probably be yelling for a long, long time. What should be true about the container that the coffee, and why?
    - Can you think of any more assumptions we should make?
- Be sure to convert all quantities into SI units (joules, seconds, kilograms, etc.). All final numerical answers should have the correct units written next to them.
- Feel free to work with your peers, but everybody must turn in a separate, original version of the assignment. It should be **handwritten, neatly**. It is due at the start of lecture, 12:45pm on Tuesday 06/22/2010. Late work will not be accepted.

Figure 4 - Coffee PBL Activity. Homework activity allowing students to explore both conceptual and calculational problems.

To keep the objectives and learning outcomes clear, it is helpful to provide a rubric with each assignment. The point of the rubric is to make the assessed qualities for each assignment clear to not only the students but also the evaluator, please see Figure 5. Students commented that the rubric allowed them to quickly identify strengths and trouble areas. The rubric also allowed for measured progress throughout the course by both the instructor and the students. Furthermore, the rubric aided assessing to take place in a timely manner allowing written homework in the first place.

Coffee PTA		
Recall of relevant thermodynamic quantities.	All necessary quantities are correctly identified, relevant and have the proper units.	3…2…1…0
	The method of heat transfer is correctly argued for and identified.	3…2…1…0
	The equation relating heat energy transferred and temperature change is correctly identified.	3...2…1…0
Relations of relevant quantities.	The relation (equation) between heat energy transferred and temperature change is properly explained.	3…2…1…0
	The relation between rate of energy transfer, amount of energy to be transferred and time is correctly determined.	3...2…1…0
Calculation of final numerical answer.	The calculation correctly uses the previously determined relation between heat energy and temperature and the relation between heat energy and rate of transfer to determine the time necessary.	3…2…1…0
	The calculation is neat and orderly and free of errors such as sign errors (e.g. plus instead of minus) and method errors (e.g. subtracting when you should have divided).	3…2…1…0
	Units are correctly converted to SI format. Final answer is correct.	3…2…1…0
Problem assessment and assumptions.	Each assumption is explained and relevant. At least three are given.	3...2…1…0
TOTAL:		**/27**
Comments.		

Figure 5 - Coffee PBL Activity Rubric. Grading and assessment rubric clearly outlining what is expected of the students for the Coffee Assignment.

Laboratories represent an area where much work needs to be accomplished beginning with well-written objectives and goals. They are also a place that could benefit greatly from PBL. As a method for giving laboratories a sense of direction, a central problem is excellent, for example, a thin lens lab based on designing eyeglasses.

Another idea for active learning in a laboratory is with IL. In such a setting, laboratories are presented as inquiries into a phenomenon, such as a Myth Busters episode. Students are given the tools and several ideas, but essentially design an experiment to investigate some aspect of the observed incident on their own.

4.7 Agenda for Future Research

Although the amount of research dedicated to TC-STEM course pedagogy has increased greatly in recent years, much necessary research remains. From the previous sections examining faculty and student perspectives, it seems that TC courses are not only useful, but in many cases preferred. STEM course pedagogy research has also made great strides in developing pedagogies that deliver desired learning outcomes. The results of these two bodies of research meld together cohesively to form a starting point for improving TC-STEM course pedagogy. Many areas remain to be studied. The following are some areas I found to be the ripest for investigation.

Much of the research describing TC courses relies on methods with a demonstrated, reliability that may only apply to regular length courses. Consider the administration of pre-tests and post-tests. In a traditionally taught class, these tests are can be twelve weeks apart, but in a TC course they may only be four or eight weeks apart. Can these data sets be compared accurately? The same goes for regular tests which appear more frequently in a TC course, than in a traditional-length course. Does a test given two weeks after a subject is taught measure the same learning gains as the same test would if it were given six weeks later, as during a traditional–length semester course?

Along the same lines is whether courses of different length can be compared meaningfully. Some TC courses slash traditional course lengths by half or quarter. Do methods that work for one TC course length necessarily work for all TC course lengths. And what about different types of TC course? Does the time-on-task greatly affect the learning experience of the students? Are certain modes of TC course better suited to some types of student than others? Are certain subjects better suited to TC courses? Perhaps courses building concept knowledge need less time-on-task than courses requiring copious amounts of practice, e.g. musical instrument mastery.

Another interesting point is that TC courses are seldom required. Instead, individuals elect to take them. In terms of research, this means that a random sample is nearly impossible to find. This, of course, leaves many open questions regarding the pedagogy, expected outcomes and utility of time-compressed courses. Most research indicates that the majority of students taking summer courses are “older, more motivated and more prepared.” This, of course, raises the question as to whether the students more likely to succeed regardless of the method of instruction. In general, the composition of the students taking TC courses needs to be examined, as well as, which students are best suited to TC courses. Another interesting question is whether the incoming attitude of the student greatly affects the learning experience of the student. Do students prepared to work hard do better than students who believe a shorter course means less work?

Chapter 5: Closing Remarks

The number of TC-STEM courses continues to rise as universities, colleges and students realize the usefulness of these accelerated learning environments. As the number and type of these courses increases, it becomes important to find the best way to ensure good learning experiences. Although present since the 1800s, TC course pedagogical research is still in its infancy, with many areas left to examine. STEM course pedagogy is also bearing new results as we find out more about the learning process in a science oriented course. Both areas of research in TC and STEM course pedagogy seem to recommend learning that includes the student in a more active role regardless of the course content, length or depth.

In STEM courses, PBL, IL and PI are yielding results by appealing to the innate curiosity that students bring with them to university. The material presented in class is examined in much the same way that scientists initially gained the understandings, through questioning phenomena, formulating solutions to real problems and discussing these solutions with colleagues.

In TC courses, these active learning frameworks need to be supplemented with organization, creativity and a willingness to involve students in discussions, process and assessment. Students in these courses require a professor who will relate to them as colleagues in learning, will learn with them and make their input as important to course progress as the course content itself.

The coming together of these two bodies of research for combined TC-STEM courses is now the focus of many new research endeavors. In an effort to continue this action, I applied as many of the conclusions of this research as I could to a pair of STEM courses taught in a TC timeframe. The research-suggested procedures included were organized, clear, specific objectives and goals, interactive course discussions facilitated by CATs and PI, group activities during laboratory practica and recitations, ILDs during class time and PBL in homework.

Comments, assessment, evaluations and grades, both final and throughout the course, indicate that the changes had an overall positive effect and resulted in the attainment of many of the aforementioned objectives and goals. Although much research remains to be examined and conducted, the results of this study lend credence to many of the suggestions and conclusions for which the literature, faculty and students argued and demonstrate qualitatively that placing the student in a position to be a *creator* of knowledge leads to a *creation* of knowledge.

Appendix – Sample Objectives

Physics 213 - Fluids and Thermal Physics - Objectives

Physics is the study of the observable phenomena in the physical world. Moreover, physics attempts to explain and predict why these observed phenomena occur. In this class, we will study several branches of physics, which deal with the movement of a substance (matter, heat, disorder and energy). By the conclusion of this course, the student will explain,

- Fluid phenomena as the collection, and movement, of large numbers of loosely bound molecules.
- Thermal phenomena as the movement of heat energy and the effects that this energy has on objects.
- Process progression phenomena as the movement of and tendency toward disorder for a large collection of molecules.
- Wave phenomena as the movement of energy through a medium.

Overall Course Goals:

1. To examine and discuss the ways in which Fluids exert force and transport matter.
2. To examine, discuss and quantize Thermal Physics by observing thermal energy's physical effect on objects, and the manner in which that thermal energy changes and flows.
3. To examine, discuss and quantize the energy stored in a gas.
4. To examine the effect that heat and energy have on the orderliness of molecules in an object and the ways in which that orderliness changes during a physical process.
5. To examine wave motion as energy motion and quantify the energy transported by a wave.
6. To further develop problem solving strategies in these and all areas of physics by classifying problems and choosing an appropriate framework/toolset.

Objectives:

1. Theme: Fluids (The Flow/Movement/Transportation of Matter)
    a. **Unit Goal: To formulate the way in which a fluids exert a force on other objects.**
        i. The student will define a fluid and state several examples and counter examples.
        ii. The student will define pressure and explain the relationship between fluids and pressure.

        iii. The student will calculate the pressure in a static fluid at any depth/height.
        iv. The student will state a working definition of Pascal's Principle and explain its application to a hydraulic lever.
        v. The student will state a working definition of Archimedes' Principle and explain its application to buoyancy.
        vi. The student will solve problems involving objects floating in fluids, Pascal's Principle and Archimedes' Principle.
    b. **Unit Goal: To formulate the way in which a fluid moves and transports matter**
        i. The student will apply the concept of the equation of continuity to situations involving fluid dynamics, such as bucket with a leak, or a partially obstructed garden hose.
        ii. The student will compare, conceptually, Bernoulli's Equation to the Law of Conservation of Energy.
        iii. The student will use Bernoulli's Equation to calculate rate of flow and pressure of fluids in motion.

2. Theme: Thermodynamics (The Flow/Movement/Transportation of Heat)
    a. **Unit Goal: To quantize the thermal energy of an object/system**
        i. The student will state the Zeroth Law of Thermodynamics and give a working definition of it.
        ii. The student will conceptualize the quantity of temperature and explain its relation to a thermometer.
        iii. The student will express the various units used to measure temperature and convert between those units.
        iv. The student will explain how the Zeroth Law of Thermodynamics allows for the existence of thermometers.
    b. **Unit Goal: To evaluate the effects that changes of thermal energy have on an object/system**
        i. The student will explain and give examples of the various effects that temperature can have on an object.
        ii. The student will use the equations governing thermal expansion to calculate the linear and volumetric expansions of objects undergoing a change in temperature.
        iii. The student will define heat.
        iv. The student will explain the effects that heat can have on an object.
        v. The student will calculate the change of temperature in an object due to heat transfer.
        vi. The student will predict a change of phase in a material and calculate the heat necessary to cause such a change of phase.
    c. **Unit Goal: To formulate the effects that changes in thermal energy have on a gas.**
        i. The student will explain the relationship between work and volumetric change for expanding/contracting gases.

   ii. The student will demonstrate the difference between work done by a system and work done on a system.
   iii. The student will state the First Law of Thermodynamics and give a working definition of it.
   iv. The student will use to First Law of Thermodynamics to describe the relation between work done by/on a system, heat added/subtracted to/from a system and the change in the internal energy of that system.
   v. The student will define, identify and graphically depict (on a p-V diagram) the four special cases of the First Law of Thermodynamics.
   vi. The student will define and give examples of the three modes of heat transfer/movement.

3. Theme: Kinetic Theory, 2nd Law of Thermodynamics, and Processes (The Flow/Movement/Transportation of Disorder)

a. **Unit Goal: To further quantize the behavior of a gas undergoing thermal changes.**
   i. The student will define an ideal gas.
   ii. The student will state the two versions of the ideal gas law and explain the conversion between them.
   iii. The student will state the method for calculating the work done by a system during each of the following processes: Isobaric, Isothermal, Isochoric.
   iv. The student will state the expression for the internal energy of an ideal gas and explain conceptually its origin from molecular considerations.
   v. The student will give working definitions of molar specific heat at constant volume and molar specific heat at constant pressure and the relationship between the two.
   vi. The student will calculate the change in temperature of a gas due to heat transfer in situations involving constant volume and in situations involving constant pressure.

b. **Unit Goal: To examine the tendency of large collections of molecules toward disorder.**
   i. The student will explain the theorem of the equipartition of energy.
   ii. The student will define an adiabatic process and use the equations of adiabatic expansions of ideal gases to calculate final temperatures, pressures and volumes of gases undergoing an adiabatic expansion.
   iii. The student will compare and contrast reversible and irreversible processes.
   iv. The student will state the entropy postulate (the 2nd Law of Thermodynamics) concerning reversible and irreversible processes.
   v. The student will mathematically define entropy and verbally state entropy's relationship to heat and temperature.

c. **Unit Goal: To apply the relations between internal energy, motion of molecules, flow of heat and flow of disorder to the physical processes used by engines and refrigerators.**

  - i. The student will give physics definitions of a heat engine, and a refrigerator.
  - ii. The student will use the principles of entropy, heat and temperature, as well as, the laws of thermodynamics to calculate the efficiency of heat engines and refrigerators described by p-V diagrams.
  - iii. The student will relate the way refrigerators and heat engines work to entropy and directionality of processes.

4. Theme: Waves and Sound (The Flow/Movement/Transportation of Energy)

- **a. Unit Goal: To visualize and develop intuition about wave motion**
  - i. The student will define waves and wave-like motion.
  - ii. The student will classify different types of waves as either transverse or longitudinal.
  - iii. The student will explain each piece of the sinusoidal wave equation.
  - iv. The student will calculate each of the following quantities, given a wave diagram: frequency, period, amplitude and wavelength.
  - v. The student will calculate each of the following quantities, given a wave equation: frequency, wavelength, wave speed, wave propagation direction, transverse wave speed and transverse wave displacement.
- **b. Unit Goal: To apply ideas about wave motion to waves on a string, sound waves and music production.**
  - i. The student will calculate the speed of a wave on a string given the string's density and the tension in the string.
  - ii. The student will describe the principles governing wave interference.
  - iii. The student will explain the Doppler Effect in terms of wavefront dynamics.
  - iv. The student will use the Doppler Effect equation to calculate the following quantities: speed of observer, speed of source, speed of wave, original frequency and observed frequency.
  - v. The student will define the following terms: standing wave, resonant frequency, fundamental mode, harmonic and oscillation mode.
  - vi. The student will use the principles governing standing waves and wave interference to explain the source of musical sound.
  - vii. The student will explain the nature of beats and beat frequency.
  - viii. The student will deduce how beat frequency can be used to tune a musical instrument.
- **c. Unit Goal: To examine waves as the movement of energy through a medium**
  - i. The student will define the energy stored in a wave in terms of previously defined variables.
  - ii. The student will examine the energy transportation of waves in terms of power, intensity and amplitude.

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