Promoting Active Learning in Calculus and General Physics through Interactive and Media-Enhanced Lectures

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ABSTRACT

In this paper we present an approach of incorporating interactive and media-enhanced lectures to promote active learning in Calculus and General Physics courses. The pedagogical practice of using interactive techniques in lectures to require "heads-on" and "hands-on" learning, and involve students more as active participants than passive receivers is a part of academic curricular reform efforts undertaken currently by the mathematics, physics and chemistry departments at North Carolina A&T State University under the NSF funded project "Talent-21: Gateway for Advancing Science and Mathematics Talents."

Key Words: Active learning, interactive lectures, media-enhanced lectures, WebAssign.

1. INTRODUCTION

The purpose of this paper is to present an approach of incorporating interactive and media-enhanced lectures to promote active learning in Calculus and General Physics courses. The pedagogical practice of using interactive techniques in lectures to require "heads-on" and "hands-on" learning, and involve students more as active participants than passive receivers is part of academic curricular reform effort undertaken currently by the mathematics, physics and chemistry departments at North Carolina A&T State University (NCA&T) under the NSF funded project "Talent-21: Gateway for Advancing Science and Mathematics Talents."

The traditional didactic fifty-minute college lecture is a teacher-centered lecturing environment in which the teacher does all the talking. Even though it is an ancient teaching method, it still remains the dominant pedagogical practice in higher education because of its ease of use and low expense. The traditional lecture format emphasizes the transmission of knowledge or information from the teacher, the holder of "expert" knowledge, to the recipients of "objective" knowledge, the student, and provides little incentive for students to actively engage in the educational process [2, 10]. It somehow handicaps the students' development of critical thinking and problem-solving skills because these skills cannot be merely taught in lectures, and they can only be learned through practice. The traditional didactic teaching method provides little opportunity for students to practice these skills in classes. In addition, the traditional lecture format fails to address the problem that the average attention span of most students is shorter than fifty minutes. Hence if a teacher keeps lecturing for a period of fifty-minutes, his/her listeners will unlikely stay alert and engaged for the entire class time. In short, the traditional lecture format is a relatively ineffective teaching technique.

Educational research has demonstrated the effectiveness of using interactive lecturing techniques to encourage active learning during the traditional expository lectures [4, 6-9]. (For instance, a report by R. Hake [6] of pre/post test data using the Halloun-Hestenes Mechanics Diagnostic test, Force Concept Inventory, or the problem-solving Mechanics Baseline test for 62 introductory physics courses enrolling a total of 6,542 students strongly suggested that classroom use of interactive engagement methods can increase mechanics course effectiveness in both conceptual understanding and problem-solving well beyond that achieved with traditional methods.) Interactive lecturing techniques stress interaction between the teacher and the learner, while promoting and enabling interactions among learners. Such a pedagogical practice involves students actively in the learning process, and enhances their opportunities to "learn", not just to be "taught". Learning in the expository lectures can increase if students' interest and activity are increased. As charted in "The Learning Pyramid" [12], "Lecture only" and "Reading" have two of the lowest rates of student retention, at 5% and 10%, respectively. Retention goes up if one adds active engagement techniques to class. For example, "Discussion Group" and "Practice by Doing" have 50% and 75% retention respectively. "Immediate Use of Learning" has a 90% retention rate. Interactive lecturing will add activities from these high retention components to the lecture.

For these reasons, we have incorporated interactive elements into Calculus and General Physics instruction in an attempt to assist students' learning by engaging them into the skill development of critical thinking and problem solving. To facilitate interactive lecturing, we utilize Smart Plug and Show classrooms along with in-class worksheets. On approximately each class day, part of the time that would typically be spent on lecture or doing more examples is used for students to answer questions and solve problems. A typical lecture will consist of approximately 30 minutes of discussing concepts, introducing equations, doing demonstrations, or solving example problems. Then, approximately 20 minutes are used for students to apply what was discussed in lecture to questions or problems that they are given in a worksheet. Lecture contents are enhanced by media materials such as PowerPoint slides of lecture notes, online supplemental resources, Maple and Java animations delivered via smart classroom facilities to aid in students' visualization and conceptual understanding.

We believe that incorporating in-class activity worksheets in Calculus and General Physics instruction and supplementing lectures with appropriate media materials have promoted active-engagement learning, oriented students' attention on application of concepts and principles and practice of problem solving skills, prepared students to apply for the same concepts and techniques on homework problems as they applied to in-class exercises, and increased interaction between students and instructors. Observing students' working and helping them solve practice problems in an interactive lecture setting allows instructors to identify what students learned and what students did not learn from lecture and hence modify instruction and assessment accordingly. In addition, working on practice problems in groups provides an opportunity for students to help each other, hence facilitating collaborative learning.

The paper is organized as follows. Section 2 describes the design and implementation of interactive lectures in Calculus and General Physics courses through incorporating in-class activity worksheets. Section 3 discusses integration of media materials into instruction to enhance lectures. Section 4 considers impact of using interactive and media-enhanced lectures on student learning. Section 5 summarizes the paper.

2. INCORPORATING INTERACTIVE LECTURING TECHNIQUES IN GATE-KEEPER COURSES

In what follows we describe our attempts to reconstitute the learning environments of students in gate-keeper courses of Calculus and General Physics to engage students to become more active and more involved learners. In the last three years, two core components of the TALENT-21 curricular reform effort have been the incorporation of interactive lecturing techniques in course instruction, and use of WebAssign, a web-based homework management and delivery system, for assessment and evaluation. The specific gate-keeper courses selected in this reform effort were Calculus, General Physics, and General Chemistry. These teaching strategies were designed to help meet the following goals in a unified, consistent manner: engage students in active learning, affect students' attitudes so that they take ownership of the learning process, and recognize and address under-preparation for these courses, especially poor algebra skills. WebAssign has become part of students' daily study routine: checking to see what assignments have been posted, printing them out, meeting with other students for group work, and submitting the answers to the assignments before the respective deadlines. A detailed account of our approach of using WebAssign as a tool to develop and deliver dynamic active-engagement assignments in Calculus and General Physics courses, to generate learning activities outside of the classroom, and to increase students' time and effort on task for the enhancement of their learning was presented in [16]. The present paper will focus on describing our effort of utilizing interactive and media-enhanced lectures to promote active learning in Calculus and General Physics courses.

To effectively incorporate interactive lecturing techniques into the traditional expository lectures, teaching strategies have to be developed, learning materials have to be prepared, and class activities have to be planned. In addition, students have to be informed of and involved into this new teaching and learning environment.

A number of successful teaching strategies and curricular materials have been developed in physics that meet those goals mentioned above in large lecture sections. Most notable are Peer Instruction by a group of physicists led by Eric Mazur [3,5] at Harvard University and Active Learning Physics Sheets (ALPS) by Alan van Heuvelen [11] at Ohio State University. In the Spring semester of 2001, for the first time, ALPS was used in General Physics for science and engineering students at NCA&T. ALPS was utilized in General Physics I to define small-group activities that help students implement the concepts and principles discussed during the lecture. The instructor of General Physics I, Aaron Titus, developed objectives for each chapter, wrote activity worksheets which targeted various objectives, and compiled a 147-page booklet containing both chapter objectives and topic-oriented activity worksheets [17]. Some worksheets focused on conceptual understanding while others focused on problem solving with an emphasis on applying principles. Formerly a class period was devoted entirely to lecturing. Now approximately half of the class time was given to students to work on the ALPS questions, and the instructor used this class-time to walk around the classroom and answer questions. This meant that lecturing must be more concise, though not necessarily less substantive. After implementing the ALPS concept for the first time in Spring Semester of 2001 in General Physics, the outcome had proved rewarding. Students seemed more involved, asked more questions, and were more focused than during traditional lectures. In addition, this type of interactive learning environment also permitted the professor to more clearly perceive when students were having difficulties. The use of ALPS has continued in subsequent semesters in General Physics I with further refinement of chapter objectives and topical activity worksheets. Because ALPS had been successful at other universities as well as NCA&T, and because the foundation of ALPS was built on solid educational research, use of it as a prototype and development of similar materials for calculus was also planned.

With the completion of restructuring four classrooms in the Marteena Hall of Mathematics and Physics into the state-of-the-arts Smart Plug and Show classrooms in Summer 2001 and consequent testing of the facilities in Fall 2001, active learning calculus worksheets were developed and incorporated in one section of Calculus II in the first time in the Spring semester of 2002. Calculus Class Activity Sheets (CCAS) were created and delivered through WebAssign. Taking advantage of recent features added to WebAssign, the instructor of the experimenting section of Calculus II, Guoqing Tang, was able to create very innovative types of CCAS questions that evaluate students during each step of solving a problem. Here is a sample class activity sheet in Calculus II on which students are required to work in small groups of three during class time and complete it one day after the class.

Class Activity #3

About this assignment

This is a class activity sheet for Section 5.4. You are given time in class to work on the problems in groups of three students. Some of you will be asked to share your solutions in class. In case you don't have enough time to complete all questions, you are asked to complete them either independently or collaboratively outside the class.

All of you are required to submit your answers online via WebAssign. It is due one day after the section is completely covered. Your responses to class activity sheet questions will be assessed as part of your homework grade.

1. [SM5.4ea(124330)] To find the arc length of the smooth curve $y = x^2 - \ln(x)/8$ on the interval $[1,e]$,

(a) you first calculate
dy/dx = [2*x-1/(8*x)]
WebEQ TechExplorer (requires plugin)

(b) you then simplify the integrand
$\sqrt{1+[\frac{dy}{dx}]^2}$ = [2*x+1/(8*x)]
WebEQ TechExplorer (requires plugin)

(c) you next find the antiderivative of the integrand
[x^2+1/8*ln(abs(x))+c]
WebEQ TechExplorer (requires plugin)

(d) you then determine the limits of integration representing the arc length
The lower limit is [1], and
the upper limit is [e, exp(1)]

(e) you finally evaluate the antiderivative at the two limits of integration respectively to obtain the arc length of the curve. (Round your answer to the nearest hundredth.)
s = [6.51405609893065]

2. [SM5.4ea(124351)] To find the arc length of the smooth curve $y = x^4/4 + 1/(8x^2)$ on the interval $[1,2]$,

(a) you first calculate
dy/dx = [x^3-1/(4*x^3)]
WebEQ TechExplorer (requires plugin)

(b) you then simplify the integrand
$\sqrt{1+[\frac{dy}{dx}]^2}$ = [x^3+1/(4*x^3)]
WebEQ TechExplorer (requires plugin)

(c) you next find the antiderivative of the integrand
[x^4/4-1/(8*x^2)+c]
WebEQ TechExplorer (requires plugin)

(d) you then determine the limits of integration representing the arc length
The lower limit is [1], and
the upper limit is [2]

(e) you finally evaluate the antiderivative at the two limits of integration respectively to obtain the arc length of the curve. (Round your answer to the nearest hundredth.)
s = [3.84375]

3. [SM5.4ea(124352)] To find the area of the surface formed by revolving the curve $y = x^2/2$ on the interval $[0,2]$ about the y-axis, you need to carry out the following steps.

(a) Calculate dy/dx = [x]
WebEQ TechExplorer (requires plugin)

(b) Simplify the expression
$\sqrt{1+[\frac{dy}{dx}]^2}$ = [sqrt(1+x^2)]
WebEQ TechExplorer (requires plugin)

(c) Determine the integrand of the definite integral representing the area of surface of revolution
[2*pi*x*sqrt(1+x^2)]
WebEQ TechExplorer (requires plugin)

(d) Evaluate the antiderivative of the integrand
[2*pi/3*(1+x^2)^(3/2)+c]
WebEQ TechExplorer (requires plugin)

(e) Determine the limits for the definite integral
The lower limit is [0], and
the upper limit is [2]

(f) Evaluate the antiderivative at the two limits of integration respectively to obtain the area of surface of revolution. (Round your answer to the nearest hundredth.)
S = [21.3216540010759]

4. [SM5.4ea(124354)] To find the area of the surface formed by revolving the curve $y = (4-x^2)^{1/2}$ on the interval $[-2,2]$ about the x-axis, you need to carry out the following steps.

(a) Calculate dy/dx = [-x/sqrt(4-x^2)]

(b) Simplify the expression
$\sqrt{1+[\frac{dy}{dx}]^2}$ = [2/sqrt(4-x^2)]

(c) Determine the integrand of the definite integral representing the area of surface of revolution
[4*pi]

(d) Evaluate the antiderivative of the integrand
[4*pi*x+c]

(e) Determine the limits for the definite integral
The lower limit is [-2], and
the upper limit is [2]

(f) Evaluate the antiderivative at the two limits of integration respectively to obtain the area of surface of revolution. (Round your answer to the nearest hundredth.)
S = [50.2654824574367].

Submit Sample for Grading

The WabAssign class activity sheet was made available to students in the same day it was used in the class. Students were asked to print the worksheet before they came to class and brought it with them when they came to the class. To insert class activity for students to work on the WebAssign activity sheets during 50-minute class time, class time was scheduled into three parts: 10-minute question and answer session, 20-minute lecturing, and 20-minute small group class activity session.

The first 10-minute question and answer session was an instructor-led session; however the instructor did not do all the talking. Students asked the instructor questions and sought answers for certain homework exercises from the instructor. The instructor sometimes refrained from answering student's questions by his own, and chose to ask some of students to give the answers instead. Whenever the time permitted, the instructor also wrote a few homework questions on the white board or displayed them on the pull-down screen through the document projector or on-board computer, and asked students to share their solutions on the white board, or displayed their solutions on the screen through the document projector, and explain their solution procedures. Other students can contribute to the session by sharing their ideas, giving hints, or correcting errors students made on the white board or the solution paper. In case a student did not know the answer to a particular question, he/she can choose to work on the problem on the spot with the help of the instructor and other students or ask some other student to rescue him/her for this problem and volunteer to answer a question at the next class meeting.

Since the lecturing time was cut roughly in half, the contents of each lecture had to be planned carefully, and delivered concisely. For this reason, partial lecture notes were prepared in PowerPoint slides. These notes were also reformatted with blank lines next to slides to accommodate students' note taking. These notes can be downloaded from the instructor's course resource website. Partial lecture notes include most "straight-forward" parts of the lectures such as the topic background information, definitions, theorems and corollaries, solution procedures, graphic illustrations, and homework assignments, leaving difficult proofs, lengthy derivation of formulas and equations, and solutions of examples for the instructor to cover during the lecturing time. Students were asked to read relevant lecture notes before each class meeting. The instructor projected the PowerPoint slides of the lecture notes on the pull-down screen through onboard computer and ceiling mounted LCD projector, and went through the notes briefly to make sure that students read the notes and understood what topics had been covered, and filled up details for the missing parts of proofs, derivations, solutions, and extensions during the 20-minute lecture time. This really helped the instructor remove time pressure in a lecture, and enable him to cover materials in depth. It also helped remove "multi-task burden" placed on students during the lecture; students were less stressful to jig between attempting to digest, and attempting to copy what is covered during lecturing [1]. The incompleteness of lecture notes gave students incentive to attend classes, and get a whole picture of what was being covered. Without the use of the Smart Plug and Show classroom facilities, it would be impossible to deliver the same amount of course content in about half of usual lecturing time. Even during this 20-minute period of lecturing, interaction between the instructor and students was still taking place with students feeling free to ask the instructor questions or clarifications, and with the instructor soliciting feedback or conjectures from students.

After concepts were explained, formulas and equations were derived, graphic illustrations were demonstrated, and example problems were solved during the 20-minute lecture time, students were asked to work on questions given in a class activity sheet in small groups of three to four students. Each activity sheet was posted through WebAssign in the early morning to allow students to print it out before class. The in-class WebAssign activity sheet questions were also projected on the screen during the group activity time. During this period of class time, the instructor walked around the classroom to observe students' work and to answer questions. Doing so allowed the instructor to identify what students learned and what students did not learn from lecture, and hence enabled him to modify instruction and assessment accordingly. Based on the instructor's observation, some students would be asked to key in their solutions to questions on computer and check their answers instantly. They might also be asked to explain how the answers were obtained. All students would be asked to submit their answers to those class activity sheet questions through WebAssign within a day, and their work was assessed as part of their homework grade. This means that all students had to work on these questions collaboratively or independently, motivating passive students to participate in learning process as well.

3. MEDIA-ENHANCED LECTURES

Interactive lectures in both Calculus and General Physics were enhanced by media materials such as online supplemental resources, Maple and Java animations.

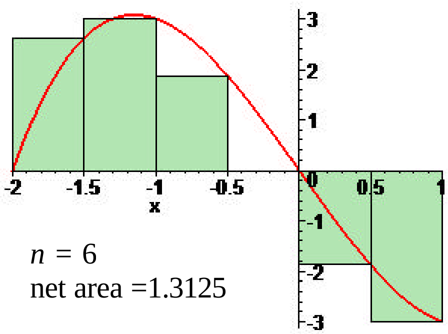
Tang used online supplemental resources, such as Mathlets: Java Applets for Math Explorations [13] and S.O.S Mathematics [15], to enhance students' problem solving skills. For instance, the Java applet named Derivative Calculator given in Mathlets specifies the differentiation rules applied in differentiating certain functions in a step-by-step fashion. Use of these Java applets sometimes requires good understanding of certain mathematical concepts, and procedural skills of problem solving. For example, another Java applet called Area between Two Curves can be used to graph two functions and the area between the two functions over a given interval, and calculate the area using the anti-derivatives of the two given functions. To correctly apply this applet, the student first has to know how to find the antiderivative of a given function. The student then needs to know how to locate the points of intersection of the two curves, and set up appropriate definite integral(s). Otherwise, the student may end up having a wrong answer. For instance, if the student wanted to compute the area between the two curves $y = x^3$ and $y = x$, and he was able to get the antiderivatives of both x^3 and x, and locate the points of intersection –1, 0 and 1. Since the area extends from –1 to 1, the student might simply put –1 and 1 as lower and upper limits of the definite integral representing the area between the two curve, and find the area equal to zero which obviously contradicts the direct observation from the graph. The area between two curves is actually represented by

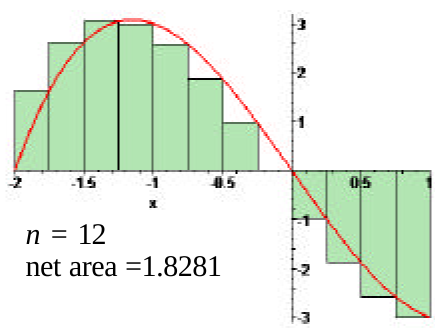
$$\int_{-1}^{1} |x^3 - x|\, dx = \int_{-1}^{0} (x^3 - x)dx + \int_{0}^{1} (x - x^3)dx = 2\int_{0}^{1} (x - x^3)dx,$$

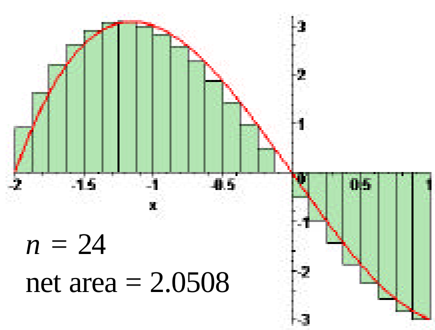
instead of the net area

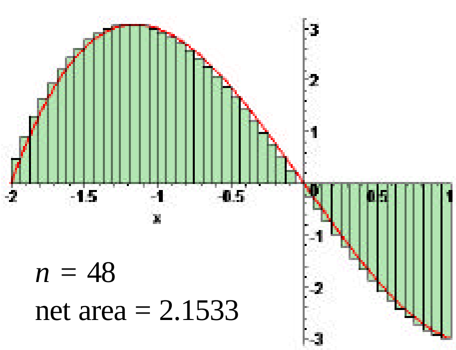
$$\int_{-1}^{1} (x^3 - x)dx = \int_{-1}^{0} (x^3 - x)dx - \int_{0}^{1} (x - x^3)dx = 0.$$

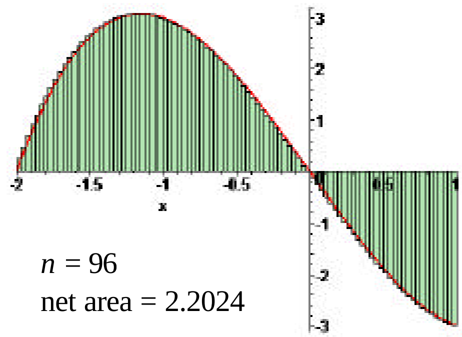
Tang also utilized Maple animations whenever appropriate to present certain fundamental mathematical concepts such as limits, continuity, geometric interpretation of the derivative, monotonicity and concavity of a function, Riemann sums and the definition of the definite integral, area between two curves, arc length of a graph, volumes of revolution, surface area of revolution, improper integrals, and convergence of Taylor series to their generated functions, graphically and aid in students' visualization. Here is a sample Maple animation describing how to use Riemann sums to approximate the definite integral of $f(x) = x^3 - 4x$ over the interval [-2,1]. The right end-point approximation is used. In the example, the graph in red color is the graph of the function. The net area of the green shaded region represents the Riemann sum for a particular partition of [-2,1] with equal length for cases when n = 12, 24, 48, and 96 respectively.

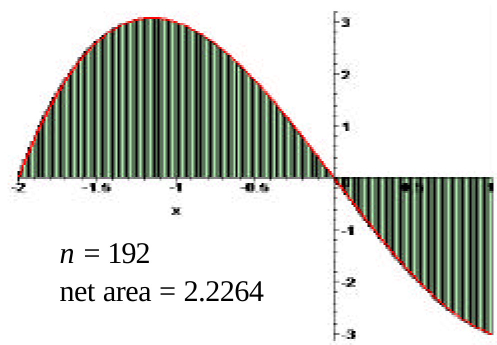












The definite integral is actually equal to 2.25 which is approximated by the Riemann sums as expected. Through this Maple animation, several complex calculus concepts such as Riemann sums, net areas, and the definite integral of a function over an interval were concisely explained graphically.

Media-enhanced lectures were especially essential to the teaching of kinematics by Titus. Titus used a new approach to teaching kinematics in the Spring semester of 2002 which seemed highly successful as evidenced by exam scores.

In the previous way of teaching kinematics, Titus taught vectors and vector algebra, then one-dimensional kinematics, and finally two-dimensional kinematics. He noticed that students tried to apply principles learned from one-dimensional kinematics to two-dimensional kinematics rather than seeing the one-dimensional case as a subset of the two-dimensional case. In addition, students didn't apply what they had learned about vectors to the vector quantities studied in kinematics. There was a major lack of connection among topics.

Therefore, Titus started with two-dimensional kinematics and introduced the concept of a vector in the context of displacement via Physlets® [14], small scriptable Java applets. This gave a concrete basis for understanding vectors and vector components. It naturally led to the concept of average velocity. Once the concept of instantaneous velocity was developed, the change in the velocity vector led to the concept of average acceleration.

This has two outcomes: (1) students benefit from repetition, a type of spiraling approach; (2) students better understand one-dimensional kinematics as a subset of two-dimensional kinematics with one of the position components being constant (which can be defined as zero).

4. IMPACT ON STUDENT LEARNING

We have attempted to incorporate interactive lecturing techniques and utilize media-enhanced lectures to engage students in the learning process and to promote "heads-on" and "hands-on" learning in Calculus and General Physics courses in the last several years. We have observed that utilizing activity worksheets in class and supplementing lecture contents with media materials have

- promoted active learning instead of passive learning among students;
- generated appropriate learning activities such as interactive and cooperative learning;
- focused students' attention on application of principles and practice of problem solving skills;
- increased interaction between instructors and students;
- prepared students to apply the same techniques and concepts on homework problems that they applied to in-class exercises.

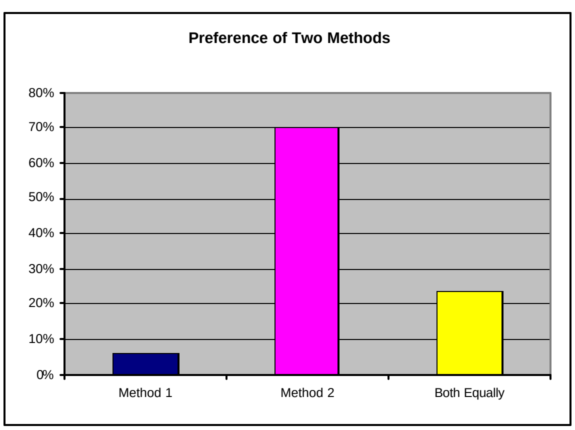
In addition, using interactive lecturing techniques has enabled instructors to identify what students learned and what students did not learn from lecture and hence modify instruction and assessment accordingly.

Most of the observations were correlated by a student opinion survey conducted in the Spring semester of 2002 on the use of in-class activity worksheets. There were 26 students from a Calculus II class and 119 students from two General Physics I classes who participated in the survey. Six questions were asked on the survey. The following is a summary of the survey results.

Question 1. Consider two options for lecture:

1. The professor lectures for 50 minutes
2. The professor lectures for 30-40 minutes and allows the remainder of time for students to answer questions on worksheets

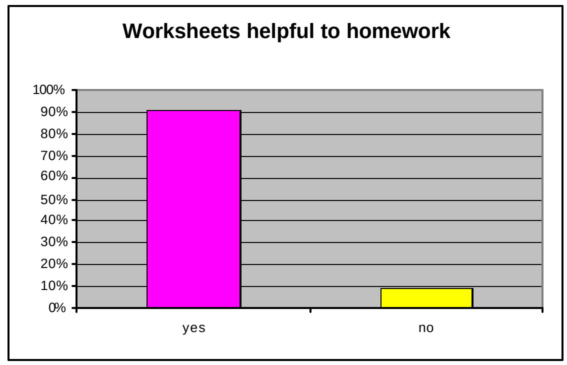
Which of these methods better helps you learn course contents?



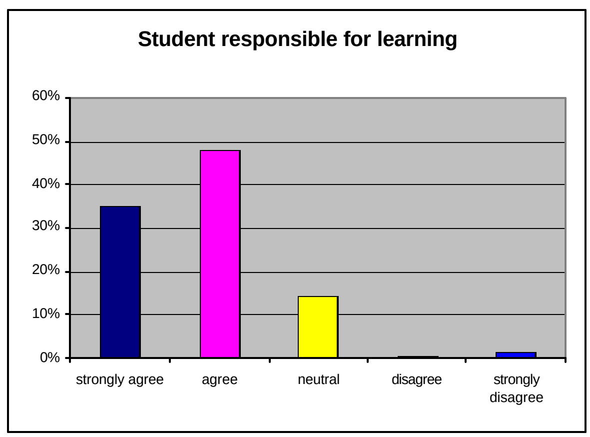
Student responses indicated that they overwhelmingly preferred the interactive lecturing format to the traditional expository lecture setting (70% versus 6%).

Question 2. Do in-class worksheets help you solve problems on WebAssign assignments?

In both Calculus and General Physics homework assignments were collected and graded via WebAssign. One of the objectives of using class activity worksheets is to prepare students to apply the same techniques and concepts on homework problems that they applied to in-class exercises. Majority of student responses (90%) confirmed that this objective was met.

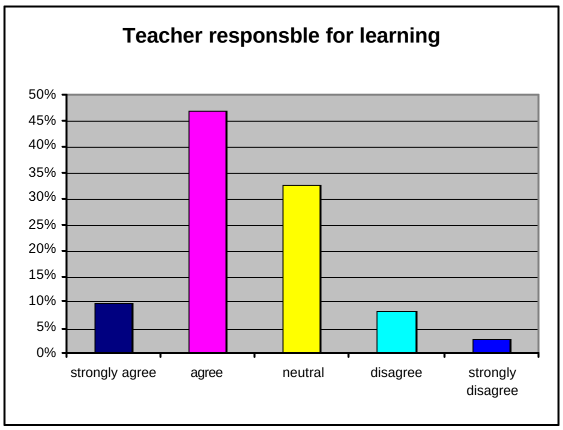


Question 3. Please indicate your agreement with the following statement. *I am responsible for learning course contents.*



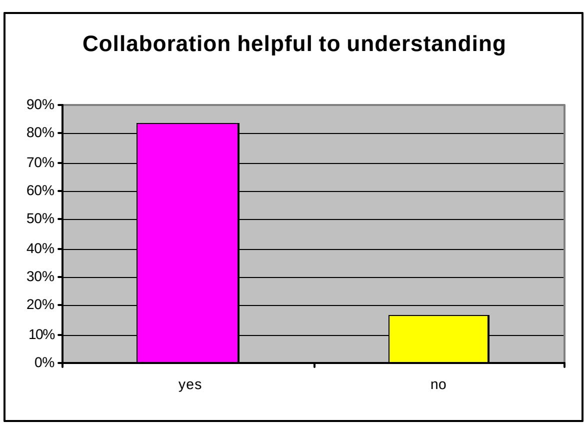
It is our hope that through exposing to interactive lecturing setting, students can gradually realize that understanding the concepts and details involved in solving problems requires effort and practice, and that they need to take "ownership" and "responsibility" to learn. This and next questions were designed to get some feedback whether this intention had been imparted into the students. The survey result indicated that 80% students agreed that they should be an active participant instead of a passive receiver. On the other hand, as revealed by the responses to the next survey question, over 57% students also think that their professors are responsible for their learning of course content. Survey results did not offer a clear distinction between the student and teacher who is primarily responsible for learning course content. We think this is partly due to the way the questions were formatted and phrased. If we combined two questions into one, and asked students who is *primarily* responsible for learning course content with three choices of response: (a) myself, (b) the professor, or (c) both, we could have gotten distinct responses and hence better feedback from students. The results of student responses to these two questions may be interpreted as that students really think both themselves and their professors are responsible for their learning, further reinforcing the importance of interactive-engagement teaching and active-engagement learning.

Question 4. Please indicate your agreement with the following statement. *The professor is responsible for my learning of course contents.*



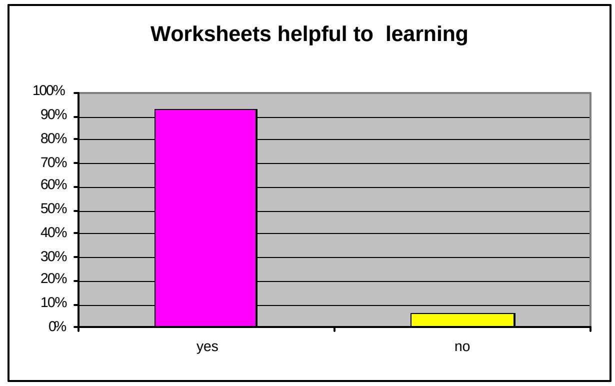
Question 5. Did collaborating with others on in-class worksheets help your understanding of course content?

Overwhelming confirmative responses (83%) indicated that the use of class activity worksheets in fact facilitated cooperative learning.



Question 6. Did in-class worksheets help you learn course content?

93% of surveyed students reported that practicing activity worksheet problems in class enhanced their learning of course content.



5. CONCLUSIONS

In both Calculus and General Physics I, we attempted to incorporate class activity worksheets to engage students in application of principles and techniques in conceptual understanding and problem solving skills enhancement exercises, and integrate media materials into lectures to aid in students' understanding and visualization of course content. Although further research is needed to determine the effect on learning, instructors' observation and students' responses to a survey indicate that the use of class activity worksheets indeed helped student learn course content and complete homework assignments, and facilitated collaboration among students and interaction between students and faculty. Finally, between the interactive lecture and traditional expository lecture formats, students overwhelmingly preferred the former to the latter.

In general, we believe that the attempt to promote active learning, and increase interaction and collaboration was successful. Students seemed more engaged, asked more questions, and were more focused than during traditional lectures. However, the experiment and its results were very preliminary, and further study needs to be carried out. Due to the sabbatical leave of the first author in the current academic year, and departure of the second author from NC A&T to take another position at High Point University in the Fall semester of 2002 (he still remains on the physics faculty at NC A&T as an adjunct professor), the follow-up study was temporarily suspended until the Fall semester of 2003 when the first author resumes his mathematics teaching at NC A&T. In our follow-up study, we will refine our design and implementation, and turn our attention toward assessing the effectiveness of classroom use of activity worksheets in both conceptual understanding and problem solving through pre/post tes t data, and normalized gain analysis.

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