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# Blending Inquiry-Based and Computer-Assisted Instruction in a Basic Algebra Course: a Quasi-Experimental Study

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# Blending Inquiry-Based and Computer-Assisted Instruction in a Basic Algebra Course: a Quasi-Experimental Study

**Abstract.** In an experiment conducted at the University of Alabama at Birmingham in Fall Semester, 2009, we compare the effect of incorporating inquiry-based group work sessions versus traditional lecture sessions in an elementary algebra course in which the primary pedagogy is computer-assisted instruction. Our research hypothesis is that inquiry-based group work sessions differentially benefit students in terms of mathematical self-efficacy, content knowledge, problem-solving, and communications. All students receive the same computer-assisted instruction component. Students are randomly assigned to a treatment (group work or lecture). Measures, including pre- and post-tests, are described. Statistically significant differences have previously been observed in a similar quasi-experimental study of multiple sections of a finite mathematics course in Fall Semester, 2008. Undergraduates who do not place into a credit-bearing mathematics course take this developmental elementary algebra course. Many pre-service elementary school teachers place into elementary algebra, thus making this course a significant component of preparing K-6 teachers.

Student success as measured by grades, and greater efficiency in terms of cost effectiveness, have been a driving force in ``course reform'' over the past 15 years, particularly at large state universities (NCAT, 2008). One prevalent direction of course reform has been the development of, and widespread use of, sophisticated computer-assisted instruction. This approach has been often applied to large-enrollment service courses in mathematics, including Basic Algebra, a non-credit developmental course, Intermediate Algebra, Pre-Calculus Algebra, and Pre-Calculus Trigonometry. Basic Algebra is taken by undergraduate students who do not place into a credit-bearing course. Traditionally, the goal of such a developmental algebra course has been to enhance students' "algebra skills." Because much of the instruction is focused on the difficulties students' have with specific algebra skills, such as dealing with rational numbers and expressions, for example, higher-order thinking may be less engaged.

**Motivating Question.** The research in this proposal investigates the relative effect of combining computer-assisted instruction with, respectively, inquiry-based group work sessions, and traditional summary lectures of material to be covered in the computer-based part. The hypothesis is that inquiry-based group work sessions differentially benefit students in terms of self-efficacy, content knowledge, reasoning and problem-solving ability, and communications.

**Theoretical Perspective.** We take the position that incorporating an inquiry-based component into a computer-assisted instructional environment may enhance student learning (compare Marrongelle and Rasmussen, 2008). We examine inquiry-based group work sessions plus computer-assisted instruction against lecture sessions plus computer-assisted instruction for effectiveness. However, what we investigate, and our methodology of simultaneously comparing different pedagogies within one term, has few direct comparisons in the literature that we have found (but see Doorn and O'Brien, 2007; Gautreau and Novemsky, 1997; Hoellwarth, Moelter, and Knight, 2005).

Our theoretical perspective is that of constructivism (Blais, 1988). Reinvention and active reconstruction is essential for the development of knowledge. Students relegated to Basic Algebra have probably been told at one time or another all the basic algebra algorithms. However, we conjecture that construction of mathematical concepts, as opposed to being told them, is far from their experience. We contend that the opportunity to construct will positively affect their self-efficacy and confidence, as well as their ability to solve problems, explain their thinking, and defend their conclusions. We contend that this will occur in conjunction with the algorithmic learning emphasized in the computer-assisted instruction.

**Prior Research.** In Fall Semester, 2008, we conducted a similar experiment in Finite Mathematics (MA 110), an entry-level course taken by non-technical students to satisfy a university mathematics requirement. The results of this quasi-experimental study (the methodology was essentially the same as described in the next section) are presented in our paper (Mayer, et al., 2009). In that study, when we compared outcomes for students participating in group work sessions versus traditional lecture, or lecture with a daily paper and pencil quiz, we found that students in the group work treatment did significantly better ($p<0.05$) comparing pre-test and post-test performance in the areas of problem identification, exhibiting problem-solving, and explaining their reasoning. All students, regardless of treatment, performed similarly (no statistically significant differences) when compared on the basis of course grades, course test scores, and gains in accuracy on the pre-/post-test items. All students exhibited similar gains in mathematical self-efficacy. There were no significant differences among treatments with regard to instructors or time-of-day. The lack of effect of treatment was contrary to our hypotheses regarding gains in accuracy and self-efficacy, but confirmed our hypotheses with regard to gains in problem identification, problem-solving, and explanation.

## Research Design and Methodology

The course we studied experimentally was Basic Algebra (MA 098), a developmental non-credit-bearing course in elementary algebra for students that did not place into a credit-bearing course. Since our goal was to compare two pedagogical treatments within an over-arching context of computer-assisted instruction, our methodology removed from consideration as many confounding factors as possible. All students involved in the courses had identical computer-assisted instruction provided. All students were required to purchase the textbook for the course, which was designed in a workbook style. 90% of a student’s grade in the course was determined by evaluation in the computer-assisted context (lab attendance, online homework, and supervised online quizzes and tests). The remaining 10% of the student’s grade, but reflecting more like 20-25% of his/her time on task, was determined by one of two pedagogical treatments, described below. The course was graded Pass/Fail based upon total number of points accumulated through homework, quizzes, tests, and lab and class participation.

Students registered for one of four time periods in the Fall 2009 semester schedule: 9 AM – Monday and Wednesday, 9 AM – Tuesday and Thursday, 10 AM – Tuesday and Thursday, or 12 Noon – Monday and Wednesday, for their 50 minute class meeting and 50 minute required lab meeting. Students in each time slot were randomly assigned to one of the two treatments. Four instructors agreed to participate in the experiment. Each instructor taught in two time slots. In one slot the instructor administered the inquiry-based group work treatment, assisted by a graduate teaching assistant, and in another time slot, the lecture treatment. Each instructor also met with each class in the mathematics computer lab. The teaching assistant who assisted with the group work treatment also assisted in the lab.

The two pedagogies compared were as follows.

- Group work (random, weekly changing, groups of four) without prior instruction, on problems intended to motivate the topics to be covered in computer-assisted instruction later.
- A traditional summary lecture with teacher-presented examples on the topics to be covered in computer-assisted instruction later.

In the group work treatment, groups worked together on a problem, but each student turned in each class meeting a written report on his/her investigation and solution of the problem(s), posed in that class period. All sections of the course received the same problem(s) for the group work. The report was evaluated based upon the same rubric as the pre/post-test. Students were aware of the rubric and received written feedback consistent with the rubric. Time was allowed in each period for one or two of the groups of four to report voluntarily on their findings to the whole class.

In the lecture treatment, the instructor gave a traditional lecture on the upcoming material. All instructors operated from the same outline of topics and objectives for each lecture, but were free to lecture in their own style. The lectures usually closely followed the workbook sections on the topics of the week.

The 10% of the final grade determined by the class meeting differed between the treatments as follows: (1) for the group work treatment, 5 points were earned for attendance and up to 5 more for evaluation of the solution and explanation turned in, and (2) for the lecture treatment, 10 points were earned for attendance, for each class meeting.

**Specific Hypotheses.** We report in this paper on two specific hypotheses regarding the two treatments.

1. Grades will be similar regardless of treatment (as measured by computerized test sum).
2. Group work treatment will have differentially improved problem-solving and communication skills (as measured by rubric).

The research in Basic Algebra was undertaken in Fall Semester, 2009. Data gathered included (1) course grades and online test scores, (2) pre-test and post-test content knowledge evaluation according to a rubric* that weighs problem identification, evidence of problem-solving, and adequacy of explanation, as well as accuracy, to extended responses on three problems typical of the material in the course and one additional problem not addressed in the course (but algebra-related), (3) pre- and post-responses to a survey of mathematical self-efficacy (Betz and Hackett, 1983; Hall and Ponton, 2002), (4) student course evaluations using the online IDEA system (Idea Center, 2009), and (5) RTOP observations of the instructors in each of the eight class meetings (Rtop, 2008). (*All students were given a copy of the grading rubric, and time to read it, prior to the pre-test.)

Subsequently, we will gather data including (6) performance of students on a one-year-delayed post-test, and (7) performance of students in the next mathematics course (either MA 110 Finite Mathematics, or MA 102 Intermediate Algebra).

In this paper we report on three specific data series related to the two hypotheses above: (1) the sum of student scores on the first four of five online tests, (2) comparison of scores on pre-test and post-test evaluated according to the rubric, and (3) comparison of accuracy gains on pre- and post-tests.

## Rubric and Rubric Training

**Rubric.** The students' solutions to the problems on the pre-test and post-test were evaluated based on a five-point rubric. All students were given copies of the rubric before taking the pre-test and post-test. The rubric contained the following specific guidelines for students:

Identify your problem (0 points or 1 point awarded)

- Take time to identify and define the problem that you are trying to solve.
- Return to your problem definition often (and perhaps redefine your goal, though this leaks into the next item).

Show Evidence of Problem Solving (0, 1, or 2 points awarded)

- Show your work and your thinking along the way.
- Don't erase! If you find an approach isn't getting you anywhere, draw a line through it, and go down a new path. (Also, you might later find you need the information that got erased.) This will show evidence of your persistence and flexibility.
- As you find something out about the problem, or about your approach, make a written note to yourself (and to the reader) on your paper. Give the reader insight into what you are thinking.
- Are you solving the problem that you initially identified? How do you know?

Explain Your Thinking (0, 1, or 2 points awarded)

- Take a moment to reflect on your results. Then reflect on how you can communicate your results.
- What did you find out? Present your findings on the problem clearly and concisely. (Some might call this "the answer," but that is only a part of complete work.)
- Give an explanation of your work appropriate to the audience (not so much your instructor, but your colleagues).
- Have you thought of any conjectures or new problems as a result of working on this problem?
- Reflect on how this problem might be connected to other problems that you have solved, or that you have been working on. Why is this problem important mathematically?

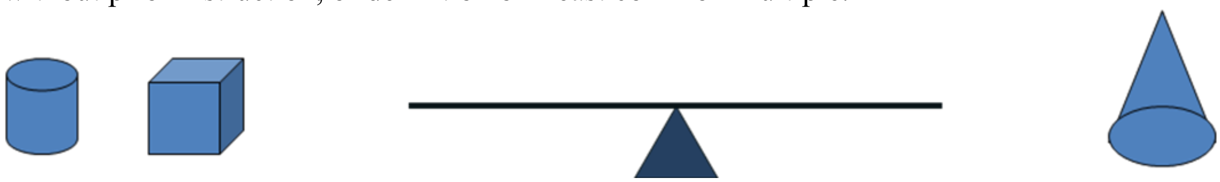
**Student Rubric Training.** Students in the group work sections of the course had their weekly work reports evaluated according to the rubric.

**Instructor Rubric Training.** Instructors and graduate assistants participated in several meetings throughout the Fall Semester designed as rubric training in order to improve the inter-rater reliability for the instructors using the rubric when scoring the pre-test, post-test, and weekly group meeting assignments. Prior to a training session, instructors and assistants were given blinded samples of student solutions to a problem and asked to score the student work. During the training session, instructors and assistants compared their ratings of solutions of student work to the rest of the training group. Differences in scoring were examined and discussed.

**Inter-Rater Reliability.** Inter-rater reliability statistics are used to assess the level of agreement among multiple raters. The purpose of doing this analysis was to estimate how consistently instructors were able to rate students' performance on each of the dimensions of the performance assessment rubric. Inter-rater reliability will be reported on elsewhere, but was deemed moderate.

## Examples of Treatments

**Example 1.** *A group work treatment problem.* Example 1 is from the fourth week of the course. The topic is "least common multiples" which would be introduced in the lecture, workbook, and online through examples. In the group work treatment, the topic is introduced through a problem without prior instruction, or definition of "least common multiple."



*Problem.* Suppose that two cylinders balance three cubes on a scale, and one cone balances two cubes on the same scale. How many cylinders would it take to balance 6 cones on this scale? Using the information given above, how many cylinders would it take to balance 351 cones? How many cylinders would it take to balance "*n*" cones?

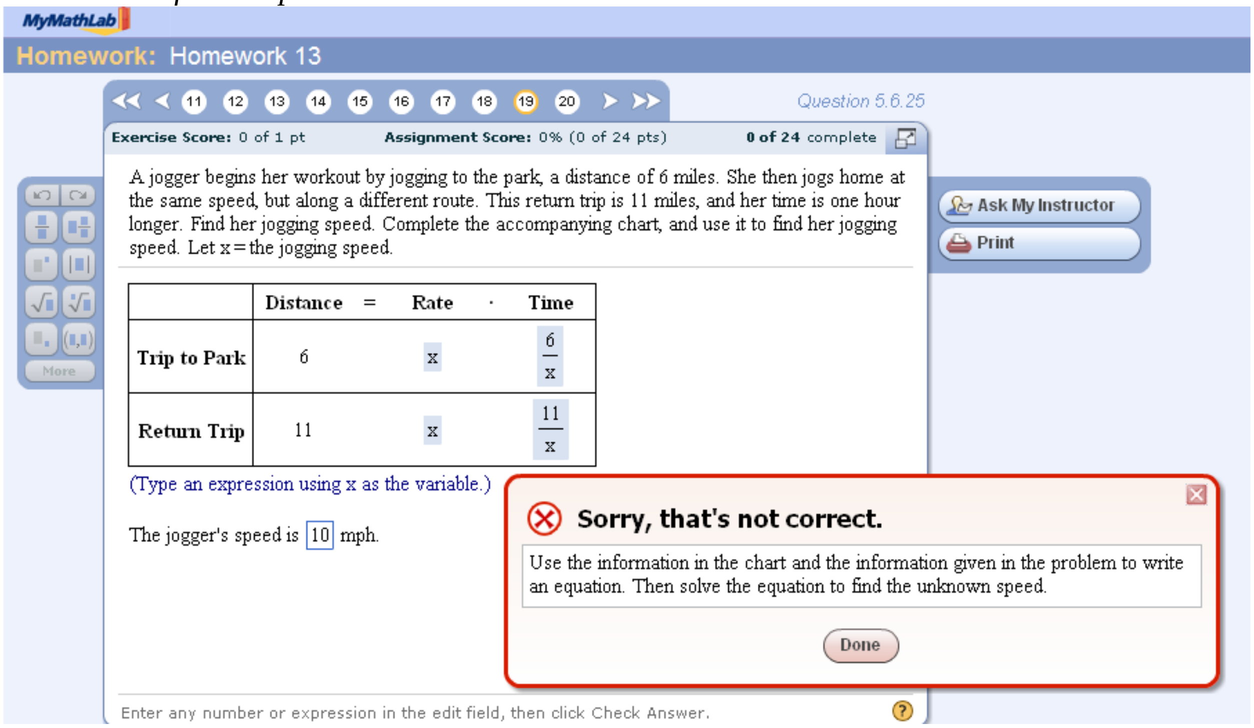
**Example 2.** *A comparison of similar problems in group session, workbook-based lecture, and posed online.* In Example 2, we compare how a "typical" distance-rate-time problem, usually presented as involving setting up a rational equation, might be presented in a group work session, in a workbook or lecture example, and in online computer-assisted instruction. The group work students would have previously seen rational equations and other motion problems involving distance, rate and time, but this would be their first experience with a word problem that might lead to a rational equation.

*Group work problem statement and directions.*
A truck travels 260 miles through a flatland route in the same amount of time that it travels through a 160-mile mountainous route. The rate of the truck is 20 miles per hour slower in the mountains than in the flatland. Find the rate of the truck on the flat route and on the mountain route.

- Discuss these problems in your group.
- Come up with a way of understanding and solving each of the problems.
- Provide a written account of your understanding.
- Consider volunteering to present your work to the class, when asked.

**Comment.** The group work problem above can be worked multiple ways. Typically, several of these ways emerge when groups are not directed to work it a specific way, such as we find in the workbook and online examples below.

*Screen shot of online problem.*




*Workbook example statement.*

Lesson #13 MA 098

**5.6 Example 7:** A truck travels 120 miles on the highway in the same amount of time it takes to travel 40 miles in the city. If the rate that the truck is traveling in the city is 30 miles per hour slower than on the highway, find the rates at which the truck was traveling both on the highway and in the city.

| | Distance | Rate |
|---|---|---|
| Highway | 120 | R |
| City | 40 | R - 30 |

Since the times are equal, we can solve this by setting the ratios equal to each other (a proportion.)

$$\frac{120}{R} = \frac{40}{R-30}$$
$$120(R-30) = 40R$$
$$120R - 3600 = 40R$$
$$120R - 40R = 3600$$
$$80R = 3600$$
$$R = 45$$

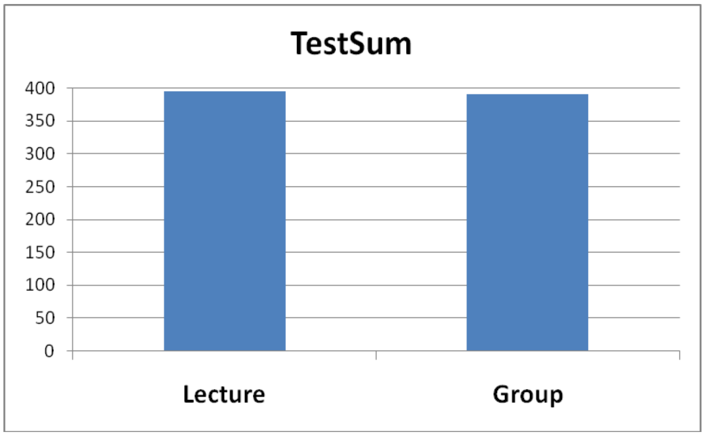
The truck is traveling 45 mph on the highway and 15 miles per hour in the city.

## Results

The following results were obtained. Analysis of data gathered continues. Further data is still to be gathered on a delayed post-test and success in subsequent mathematics courses.

### Hypothesis 1. Grades will be similar regardless of treatment.

Hypothesis 1 was supported. There was no significant difference ($p<0.05$) between treatments for the sum of the first four of five tests.




N=300
Lecture=149
Group=151

Test five was omitted because students could elect not to take it if they already had a high enough point total to pass the course. Two-way ANOVA was used to detect differences among instructors. No significant differences were found for Instructor, Treatment, or Instructor*Treatment. By way of example, the ANOVA table for Instructor is reproduced below.

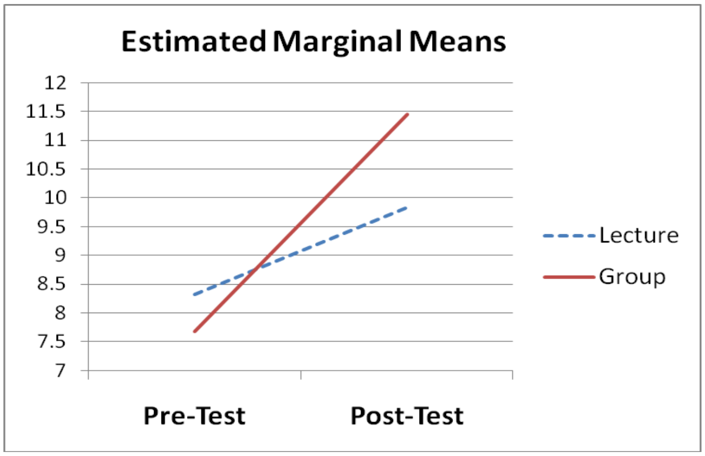
**2. INSTRUCTOR**

Dependent Variable:TESTSUM

| INSTRUCTOR | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Instructor 1 | 395.205 | 8.464 | 378.547 | 411.863 |
| Instructor 2 | 386.528 | 7.866 | 371.047 | 402.009 |
| Instructor 3 | 394.365 | 8.145 | 378.334 | 410.395 |
| Instructor 4 | 398.299 | 8.292 | 381.980 | 414.619 |

### Hypothesis 2. Group work treatment will have differentially improved problem-solving and communication skills.

Hypothesis 2 was supported. There was a significant difference in the rubric scores in favor of the group work treatment. Repeated Measures ANOVA (Wilks' Lambda), and univariate analysis of difference scores, each indicated significant differences at $p<0.05$. The rubric included evaluation of problem identification, problem-solving, and explanation, but not accuracy. The pre/post test had four problems with a maximum rubric score of 5 on each.




N=234
Lecture=115
Group=119

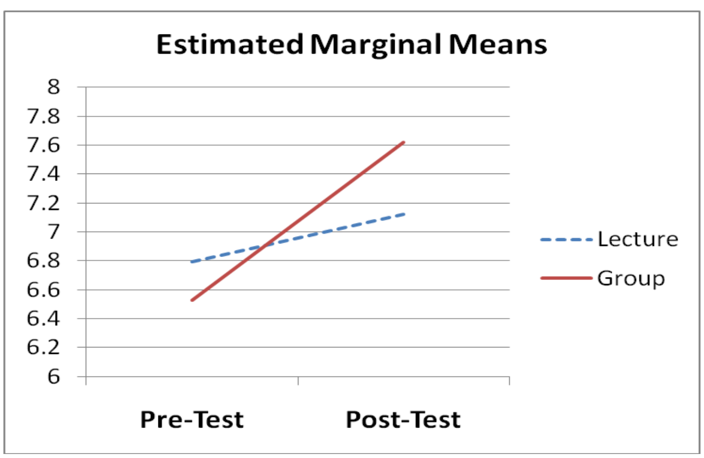
Wilks' Lambda
Time: $\lambda$=0.562
Time*Treatment: $\lambda$=0.876

Pillai's Trace, Hotelling's Trace, and Roy's Largest Root confirmed these results. There were no significant diffrences for Time*Instructor or Time*Treatment*Instructor. A univariate analysis of difference scores comparing instructors in pairs, but without regard to treatment, did indicate a significant difference between one pair of instructors.

The drop from 300 taking the first four tests to 234 taking the post-test was probably caused by the grading system adopted for the course. Since the course was graded pass/fail, students who had earned sufficient points to pass the course before the fifth test and the post-test had lessened motivation to continue. This data attrition affected both treatements about equally. We have switched back to ABCDF grading of MA 098 effective Spring Semester, 2010.

**Accuracy.**

The pre/post-test was evaluated for accuracy on a scale of 0-10. Two of the four questions had multiple parts, and each part of a question was assigned 0 or 1 for accuracy. There was a significant effect ($p<0.05$) pre- to post- for both treatments taken together, and a significant difference ($p<0.05$) pre- to post- in favor of the group work treatment. This result is in contrast to the accuraacy result we found in our previous studey of Finite Mathematics in Fall, 2008, where there was no significant difference between treatments.




N=233
Lecture=115
Group=118

Wilks' Lambda
Time: $\lambda$=0.872
Time*Treatment: $\lambda$=0.960

Though the difference between treatments was statistically significant, the multiple parts meant that the four questions were not weighted equally in the accuracy analysis. We are analyzing the results more carefully to see of the difference can be ascribed to just one of the questions. For a subsequent experiment in Fall Semester, 2010, with the same course, we are revising the pre/post-test to include three constructed response questions similar to those curently being used, and at least 10 objective (multiple choice) questions of established reliability for testing algebra knowledge relevant to the course.

## Conclusions and Implications

We draw the following conclusions and implications from the study.

1. The inclusion of a group work class meeting in lieu of a weekly lecture does not appear to affect adversely student success as measured by grades
2. Group work does have a positive effect on problem-solving and communications abilities (as measured together by our rubric-based score).
3. Group work may have a positive effect on accuracy.

This research will inform our teaching of Basic Algebra. In Spring Semester, 2010, we will teach all sections of Basic Algebra using the group work treatment. Though this will not be a comparison study, we will continue to gather data to corroborate the results of the research reported above.

We expect to study to Basic Algebra further in Fall Semester, 2010, and extend our study to, Intermediate Algebra, Pre-Calculus Algebra (Oerhtman, Carlson, and Thompson, 2008), and Pre-Calculus Trigonometry, using essentially the same experimental design, in subsequent semesters. Having multiple sections of a course usually on offer makes it relatively easy to implement this quasi-experimental design.

Many pre-service elementary school teachers start in the non-credit course, Basic Algebra, and take Intermediate Algebra, and Pre-Calculus Algebra, in addition to Finite Mathematics. As part of our NSF-supported Mathematics and Science Partnership, we have designed courses that emphasize mathematical reasoning and are entirely inquiry-based. These include two recommended for pre-service elementary teachers: *Patterns: the Foundation of Algebraic Reasoning*, and *Geometry and Proportional Reasoning*. The same courses are required for pre-service middle school teachers in the Mathematical Reasoning track in the Mathematics Major at UAB. Studies are underway in these two courses. As yet few pre-service elementary teachers take both of the recommended newly-designed courses. One long-term goal of our research program is to provide evidence that the recommended courses are substantially better in terms of student learning for pre-service teachers.

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## References

Betz, N. E. and Hackett, G. (1983). The Relationship of Mathematics Self-Efficacy Expectations to the Selection of Science-based College Majors. *Journal of Vocational Psychology*, *23*(3), 329–345.

Blais, D. M. (1988). Constructivism – a Theoretical Revolution for Algebra. *Mathematics Teacher*, Nov. 1988, 49–56.

Doorn, D. and O'Brien, M. (2007). Assessing the Gains from Concept Mapping in Introductory Statistics. International Journal for the Scholarship of Teaching and Learning 1(2); retrieved from http://academics.georgiasouthern.edu/ijsotl/v1n2/articles/doorn/index.htm.

Gautreau, R. and Novemsky, L. (1997). Concepts First-a Small Group Approach to Physics Learning. *Am. J. Phys.*, *65*(5), 418–429.

Hall, M. and Ponton, M. (2002). A Comparative Analysis of Mathematics Self-Efficacy of Developmental and Non-Developmental Mathematics Students. Preprint (Presented by Michael Hall at the 2002 meeting of the Louisiana/Mississippi Section of the Mathematics Association of America.)

Hoellwarth, C., Moelter, M. J., and Knight, R. D. (2005). A direct comparison of conceptual learning and problem solving ability in traditional and studio style classrooms. *Am. J. Phys.*, *73*(5), 459–463.

The IDEA Center (2009). Website: http://www.theideacenter.org/our-services/student-ratings-instruction/0030-idea-online

Marrongelle, K. and Rasmussen, C. (2008). Meeting New Teaching Challenges: Teaching Strategies that Mediate Between All Lecture and All Student Discovery. In M. Carlson and C. Rasmussen (Eds.), *Making the Connection: Research to Practice in Undergraduate Mathematics* (pp. 167–178). Mathematical Association of America, Washington, DC.

Mayer, J., Cochran, R., Stansell, L., Land, H., Fulmore, j., Bond, W., Argo, J., and Rehm, A. (2009). Incorporating Inquiry-Based Class Meetings with Computer-Assisted Instruction, Proceedings of the 12th Annual Conference on Research in Undergraduate Mathematics Education, Raleighh, NC, February, 2009.

National Center for Academic Transformation (2009). Website: http://www.center.rpi.edu/PCR/Proj Model.htm

Oerhtman, M., Carlson, M., and Thompson, P. (2008). Foundational Reasoning Abilities that Promote Coherence in Students' Function Understanding. In M. Carlson and C. Rasmussen (Eds.), *Making the Connection: Research to Practice in Undergraduate Mathematics* (pp. 65–80). Mathematical Association of America, Washington, DC.

SPSS Base 7.5 Applications Guide (1997), Chicago, IL.

Reformed Teaching Observation Protocol (2008). Developed by ACEPT Project (Arizona State University). Website: http://physicsed.buffalostate.edu/AZTEC/RTOP/RTOP full/