From innovation to implementation:
Multi-institution pedagogical reform in undergraduate mathematics

A summary of research results

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I. Study questions

- What are the *student outcomes* of undergraduate math courses using inquiry-based learning (IBL) methods—including learning, attitudes, beliefs, career and education interests?
- How do these outcomes *vary* among student groups? And how do they *compare* with those of other types of courses?
- By what *processes* do these outcomes arise? What are the roles of students, instructors, TAs, course materials, and classroom practices?
- What are the costs and benefits for *instructors* and *departments* who use IBL methods?

II. Characteristics of the study sites and the study design

The study sites, four research math departments with privately funded "IBL Centers," shared general aims for students' intellectual development or mathematical maturation, and a general pedagogical approach emphasizing student creation, communication and critique of ideas.

But their activity was quite varied, with ~40 IBL courses but few in common across sites. The courses were varied in content, student audience, and forms of IBL. Departments had distinct contexts and cultures, though all had some record of prior innovation around math education.

∴ This quasi-experimental study thus examines a realistically messy, multi-site implementation of educational reform. This is what reform looks like when implemented on a scale that matters.

The measures used were broad, not content-specific, to accommodate the variety of courses and sites. Data include 300 hours of classroom observation, 1100 surveys, 110 interviews, 220 tests, and 3200 academic transcripts, gathered from >100 course sections at 4 campuses over 2 years.

III. What is IBL? The implementation of inquiry-based learning

Classroom observation was used to verify that the IBL classes (designated by each Center) were indeed different from non-IBL sections of the same course. On average over 60% of IBL class time was spent on student-centered activities including problem presentations, discussion, small group and computer work, while students in non-IBL courses spent 87% of class time listening to their instructors talk. IBL courses also showed more variety in classroom activities, and more student leadership and question-asking. They were rated more highly for a supportive classroom environment, students' intellectual contributions, and in-class feedback to students on their work.

Differences in instructor-centered behaviors were small, suggesting that course outcomes depend more on teachers' choice of instructional activities than on their intent or interest in students. Students' accounts highlight individual engagement in meaningful mathematical tasks and collaborative processing of mathematical ideas as central to their learning.

IV. Student outcomes: Selected results

1. After an IBL or comparative course, IBL students reported higher learning gains than their non-IBL peers, across cognitive, affective, and collaborative domains of learning.
2. IBL students' attitudes and beliefs changed pre- to post-course in ways that are known to be more supportive of learning, compared to students who took the non-IBL sections.

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3. In later courses, students who had taken an IBL course earned grades as good or better than those of students who took non-IBL sections, despite having "covered" less material.
4. On a research-based test of students' ability to evaluate proofs, IBL students showed evidence of greater skill in recognizing valid and invalid arguments and of the use of more expert-like reasoning in making such evaluations. The volunteer sample consisted of only high-ability students; no instructors gave the test to all students during class time.
5. On a validated test of mathematical knowledge for teaching, pre-service teachers who had taken a math course targeted to their needs (K-6, K-8 or 6-12, site-dependent) scored above the mean for a large national sample of in-service teachers. All groups' scores improved pre to post (effect size 0.8), but rose most for students who scored lowest on the pre-test. No non-IBL sections of these pre-service courses were available for comparison.

Results by gender

6. Non-IBL courses show a marked gender gap: women reported lower learning gains and less supportive attitudes than did men (effect size 0.4-0.5). Women's confidence and sense of mastery of mathematics, and their interest in continued study of math, was lower. This difference appears to be primarily affective, not due to real differences in women's mathematical preparation or achievement.
7. This gender gap was erased in IBL classes: women's learning gains were equal to men's, and their confidence and intent to persist similar. IBL approaches leveled the playing field for women, fixing a course that is problematic for women, yet doing no harm to men.

Results by achievement group

8. When sorted by prior achievement, the grades of most students (IBL and non-IBL alike) dropped in subsequent courses as course work became more difficult. But grades of initially low-achieving students who had taken the IBL course rose 0.3-0.4 grade points, unlike their low-achieving, non-IBL peers, and unlike their higher-achieving classmates.

V. Publications (to date) https://www.colorado.edu/eer/research-areas/student-centered-stem-education/inquiry-based-learning-college-mathematics

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