Student Outcomes from Inquiry-Based College Mathematics Courses: Benefits of IBL for Students from Under-Served Groups

Contributed Research Report

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Abstract

Our large, mixed-methods study examines cognitive and affective outcomes of inquiry-based learning (IBL) in a variety of undergraduate mathematics courses at four universities. Student outcomes are measured by pre/post-survey items, self-reported gains and historical transcript data. Students in IBL courses report higher cognitive and affective gains than do non-IBL students. IBL students also report increase in motivation and interest, whereas non-IBL students' motivation drops after mathematics courses. The historical transcript data also shows IBL students' higher interest compared to their non-IBL peers. These benefits of IBL instruction are especially important for women and low achieving students, who are often under-served by the traditional college mathematics courses. Our findings suggest that IBL instructional methods support positive learning outcomes in various groups of students, including those under-served and under-supported by the traditional college mathematics courses.

Keywords: inquiry-based learning, mixed methods, learning outcomes, undergraduate students

Introduction

Inquiry-based learning (IBL) refers to teaching and learning approaches that engage undergraduates in learning new mathematics by exploring mathematical problems, proposing and testing conjectures, developing proofs or solutions, and explaining their ideas. Thus students both "learn new mathematics through engagement in genuine argumentation" and come to "see themselves as capable of reinventing mathematics and to see mathematics itself as a human activity" (Rasmussen & Kwon, 2007, p. 190). Such approaches are supported by current socio-constructivist views of learning that emphasize individual constructions and ways of thinking and learning developed in social interactions in classrooms (Bransford et al.,1998; Cobb et al., 2000; Davis, et al., 1990). For college students in science and engineering, inquiry appears to be more effective than traditional instruction at improving academic achievement and developing problem-solving (Prince & Felder, 2007). However, fairly little empirical evidence exists to demonstrate the impact of IBL methods on student learning in college mathematics. Exceptions include studies by Smith (2006), Jensen (2006), Kwon, Rasmussen and Allen (2005), Ju and Kwon (2007), and Rasmussen et al. (2006). These studies suggest that undergraduate students' ideas of mathematics, proofs, and their own role in doing mathematics can be affected by the social norms and classroom practices that emphasize student activity, problem-based learning, and classroom discussions. This raises interesting new questions: how and to what extent do IBL experiences influence undergraduate students' motivation, achievements, and choices in learning mathematics?

Our group has conducted a large, mixed-methods study of IBL mathematics courses taught at four campuses where "IBL Centers" have been established. The courses range from introductory to advanced college mathematics and target varied audiences including math majors, science and engineering majors, and pre-service teachers. Observation, survey, interview and test data were gathered from over 100 course sections across two years, most from

IBL sections but also from non-IBL sections of the same courses, where these were available. In addition, student academic records for over 5000 students were obtained so that we could examine patterns in student achievement and course-taking following an IBL (or non-IBL comparative) course. In this report, we consider multiple measures of two main types of outcomes, broadly described as cognitive and affective outcomes, for students from these IBL courses and comparison sections. We examine key differences among student groups that suggest that IBL methods particularly benefit some groups of students who are often under-served by traditionally taught college mathematics courses: women and low-achieving students.

Methods

The study used several different measures for cognitive outcomes, including self-reported learning gains from surveys, academic achievement measures from transcripts, and test data from a subset of courses. Multiple measures for affective outcomes included self-reported affective changes from pre/post survey items and pursuit of additional mathematics courses, which we took as a proxy for increased interest in mathematics or commitment to it as a discipline, in parallel to survey items that explored these interests. We also explored cognitive and affective gains, and how these came about, in interviews with 68 IBL students.

Pre- and post-surveys were obtained from 800 IBL and 400 non-IBL students on cognitive, affective and social aspects of student learning and experiences during their math course. Longitudinal measures are based on pre/post items grounded in theory and constructed to probe students' mathematical beliefs, affect, goals and strategies of learning and problem solving on a seven-point Likert scale. Gains in understanding, thinking, attitudes, confidence and capabilities are measured at the end of courses on a five-point scale from "no gain" to "great gains" that is based on the SALG instrument (Student Assessment of their Learning Gains, 2008), developed to gather formative and summative data on classroom practices. The composite variables were constructed on the basis of the designed scales, exploratory factor analyses, and item analyses. The surveys also gathered information on students' personal and mathematical backgrounds and were matched using a unique identifier.

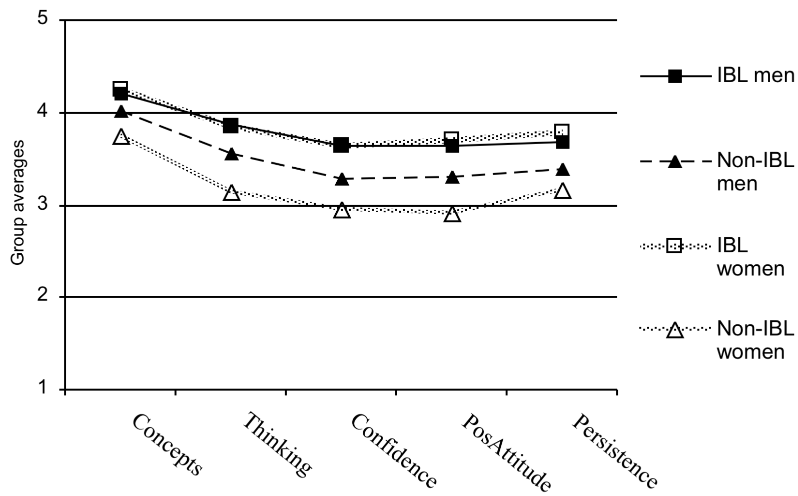
Historical transcript data for 5563 students at 3 campuses included mathematics courses taken, grades obtained, majors and minors, and some backgrounds (by academic term) for samples of students who took an IBL or non-IBL version of the same course in specific semesters, and allowing time for most students to complete subsequent mathematics courses and college degrees. Composite variables were constructed to measure students' incoming mathematical background, overall academic preparation, course outcomes, and post-course outcomes, such as number of additional math courses taken, average grades in all, required, and elective courses. For both survey and transcript data, results are based on statistical analysis including descriptive statistics and parametric or non-parametric tests.

Findings

Survey measures provide the strongest measures of both cognitive and affective outcomes for IBL students, but academic records and test data provide several points of corroborating evidence. Overall, IBL students reported higher gains than their non-IBL peers on both cognitive and affective survey measures. For example, IBL students reported higher gains in understanding concepts, mathematical thinking, confidence in doing and communicating about mathematics, persistence, and positive attitude about mathematics learning. Moreover, IBL students preserved their high motivation and increased their interest in college mathematics, whereas non-IBL students' motivation to graduate in mathematics clearly dropped during a conventional course. Pre-service teachers benefited less from the IBL instructional approaches than the non-teaching track IBL students.

Some IBL instructors interviewed for this study hypothesized that women would especially benefit from the collaborative style and confidence-building typical of IBL courses. They suggested that, while high-achieving students were not harmed by IBL courses, and often enjoyed them very much, students with more modest records of achievement would benefit most from this teaching style. We thus examined survey data for these sub-groups. Both men and women in IBL courses reported higher learning gains than their non-IBL peers, but the gains for women were striking. IBL women scored high on all cognitive and affective gains, whereas non-IBL women reported the lowest gains. This strongly indicates that women are underserved by non-IBL courses, whereas they clearly benefit from the IBL experience.

Differences between IBL and non-IBL students are statistically highly significant ($p<.001$) both among men and women.



Breaking out the students by prior achievement levels (using their self-reported college GPAs) is also illuminating. We divided the groups in rough thirds, according to their self-reported college GPA: top (≥3.8), high (3.0-3.79), and moderate or low (<3.0). It appeared that lower achieving students' cognitive gains were higher in IBL courses. The results indicate that traditional methods benefit stronger students the most. While IBL methods are beneficial to all types of students, the learning gains are greater for IBL students who started with the lower scores. These differences in gains were particularly apparent among pre-service teachers. However, as first-year students did not report a previous college GPA, the sample size is smaller for this result and do not reflect situation for all students.

Analysis of academic records data indicates that some of these gains may outlast the course itself. For example, for one campus with large IBL enrollments, we divided students in rough thirds based on their math GPA prior to the IBL class (or comparable non-IBL section): high (>3.4), medium (2.5-3.4), and low (<2.5). Our analysis shows that the low-scoring IBL students get higher average grade on the later required math courses than their non-IBL peers. Thus, IBL experience boosts achievement for the initially low-achieving students, while traditional courses show no such benefit. On the other hand, there is no evidence that the IBL methods disadvantage medium and high-achieving students. On the contrary, our analysis indicates that high-achieving IBL students take significantly more IBL-method math classes than their non-IBL peers. As greater number of math classes taken (including IBL-style) represents greater interest in mathematics, the analysis shows that taking an IBL course fosters greater interest in mathematics among high-achieving students. In sum, the previously low-scoring students benefit in achievement, while the high-scoring student get a boost in interest and motivation. Thus, the faculty prediction on the benefits of IBL is supported by our transcript data.

The evidence to date from math test results is less detailed. However, the above findings are corroborated by results of a pre/post test of mathematical knowledge for teaching (Hill, Schilling & Ball, 2004) given to students in IBL courses for pre-service teachers. The pre-to-post improvement in test score was greatest for students who answered fewer than 50% of items correct on the pre-test. That is, low-achieving students in IBL math courses for teacher preparation made greater gains than did their higher-scoring peers.

In sum, multiple measures of students' cognitive and affective outcomes from college mathematics courses taught with IBL methods indicate that students benefit from these approaches to teaching and learning. Indeed, in no case do the student outcomes favor the non-IBL group. And two groups of students who are often under-served by traditional courses benefit in particular from their experiences in IBL classrooms: women, who in many departments are underrepresented in mathematics, and students who are not already high-achievers in mathematics. Such positive outcomes of IBL instruction in college mathematics should justifiably get attention of undergraduate mathematics educators. IBL provides powerful tools for enhancing learning outcomes of undergraduate mathematics students, especially those under-served by the traditional college mathematics courses.

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