What has Ally Learned?
Outcomes for Students and Teachers of IBL Mathematics Courses

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Overview of the project

Large, mixed-methods study of inquiry-based learning (IBL) as implemented in 4 research mathematics departments with “IBL Centers” established in 2004

1) What are the student outcomes of IBL mathematics courses?
   • Math learning & thinking; affective and social outcomes

2) How do these outcomes vary among student groups?
   • IBL vs. non-IBL courses, but also...
   • …by gender; course type; achievement level; etc.

3) By what processes do these outcomes arise?
   • the roles of students, instructors, TAs; classroom practices
**Conceptual design of the study**

<table>
<thead>
<tr>
<th>2 types of courses</th>
<th>Math learning &amp; thinking: <em>external measures</em></th>
<th>Math learning &amp; thinking: <em>student self-report</em></th>
<th>Attitudes &amp; beliefs</th>
<th>Longer-term impacts</th>
<th>Classroom processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math track (intro &amp; advanced)</td>
<td>~120 “Proof tests” *</td>
<td>~1200 surveys of learning gains *</td>
<td>~800 matched pre/post surveys of attitudes &amp; beliefs *</td>
<td>~3200 academic transcripts* Interviews</td>
<td>~300 hrs of classroom observation * 44 interviews with instructors</td>
</tr>
<tr>
<td>Teaching track (pre-service K12)</td>
<td>~100 LMT tests, pre/post</td>
<td>68 interviews with students</td>
<td></td>
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</table>

Comparison with non-IBL sections where possible *
Emphasis on “signature” IBL courses on each campus
Checkerboard of interlinked studies for triangulation
Studying real-world education reform

Inherent variety in courses & audiences
- 4 departments teaching ~30 classes
- Targeted to 1st-year students, intro to proof, math majors, pre-service K-12 teachers
- Many math topics

Varying definitions and practices of “IBL”
- Campus cultures
- Methods & levels of instructor development & mentoring vary
- Some “non-IBL” courses also use active learning

- Variety broadens the definition of what exactly is being evaluated
+ …but enables linkage of outcomes with practices along a spectrum
+ These are realistic implementations of IBL… *not* an idealized scenario
What *is* inquiry-based learning?
IBL classrooms: Instructors’ aims

Get students to …

Engage in the material

Figure things out for themselves and therefore understand them deeply

Explain it to somebody else and thereby make it their own

Learn how to learn new and difficult things

Develop confidence that your answer is right, even if someone with authority hasn’t told you.
Deep engagement + collaboration…

I do have to work harder, but I feel like when I’ve finished a proof, I’ve actually accomplished something.

Once you spend time alone with it, then talking to other people really helps solidify it.

You can’t just write the proof up on the board and expect everybody to get it—you need to really explain it. And explaining it further helps me get it too.

We have to work in the group—we can’t do this alone.

Side effects: persistence, payoff of effort, responsibility to others; communication skills, confidence, seeing multiple routes to solution
Mean instructional practices in IBL and non-IBL classrooms

IBL: 
**Student**-centered activity

Non-IBL: 
**Instructor**-centered activity
### IBL courses also differ in other ways

<table>
<thead>
<tr>
<th>On average…</th>
<th><strong>IBL</strong></th>
<th><strong>Non-IBL</strong></th>
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<tbody>
<tr>
<td>IBL classes change gears more often</td>
<td>8.6 activities/hr</td>
<td>3.3 activities/hr</td>
</tr>
<tr>
<td>Students take the lead more often</td>
<td>57% of class time</td>
<td>6% of class time</td>
</tr>
<tr>
<td>(student, group, class as a whole)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Students ask more questions, per hour</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>…and more students ask at least 1 question in any class period</td>
<td>33% of students</td>
<td>14% of students</td>
</tr>
</tbody>
</table>

**Observer ratings of extent of…**

(14 items total, scale 1-5)

| Student-student interactions (3 items) | 3.31 | 1.43 |
| Student-instructor interactions (7)    | 3.34 | 1.75 |
| Joint responsibility for course direction (2) | 2.31 | 0.97 |
| Instructor sets atmosphere, summarizes (2) | 3.70 | 3.50 |
Variation of instructional practices in IBL and non-IBL classrooms
IBL classrooms: Observed activities

- Students solve challenging problems alone or in groups; share solutions; analyze, critique & refine their solutions
- Class time is used for these student-centered activities; students play a leadership role; activities change often
- Course is driven by a carefully built sequence of problems or proofs, rather than a textbook
- Pace is set by students’ progress through this sequence
- Course goals usually emphasize thinking skills & communication; content “coverage” is less central
- Instructor serves as “guide on the side” not “sage on the stage”—manager, monitor, summarizer, cheerleader
What are the student outcomes of IBL instruction?
Three claims about student outcomes

1. IBL instruction has positive outcomes for students
2. Especially women
3. And students with lower levels of prior achievement
**General measures of student outcomes**

*Learning gains*: **cognitive** (math thinking, understanding concepts, application of math knowledge, teaching). Also **affective** gains.

- From post-survey (SALG-M) section, “How much did you learn…”
- Composite variables from several survey scales; range from 1-5

<table>
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<tr>
<th>IBL math track</th>
<th>Non-IBL math track</th>
<th>IBL pre-service teachers</th>
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<tr>
<td>563</td>
<td>288</td>
<td>220</td>
</tr>
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*Grades*: average grades from required, elective, & IBL classes taken after the target class; average target grade, next semester GPA. Also **course-taking patterns**, number of courses taken.

- From student academic records for one course, one university
- Constructed variables that exclude W/Q, I, CR/NC from averages
- Include grades for repeat attempts of taking a class

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<th>Non-IBL math track</th>
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<td>211</td>
<td>1130</td>
</tr>
</tbody>
</table>
IBL: N= 503-530; Non-IBL: N= 294-328;  IBL pre-service teachers: 166-168.
Scale from 1 = no gain to 5 = great gain

Cognitive gains from survey
Affective gains from survey

IBL: N=520-529; Non-IBL: N=320-325; IBL pre-service teachers: N=166.

Scale from 1 = no gain to 5 = great gain

- Confidence
- Positive Attitude
- Persistence
Summary of findings, IBL vs. non-IBL

*Self-reported learning gains* - cognitive, affective, social - are highest overall for IBL math-track students. are highest for IBL pre-service teachers in application, teaching

*Interviews* corroborate these gains & their nature

*Attitudes* (pre vs. post-course)

  Interest in mathematics as a major; as a personal interest

    increases modestly for IBL students

    declines slightly for non-IBL students

*Tests* show that IBL students apply *slightly more sophisticated* criteria when evaluating mathematical arguments

*Later courses*

  IBL students earn grades as good or better than peers

  IBL students take as many or more courses
Cognitive gains from survey, by gender

Affective gains from survey, by gender

Scale from 1 = no gain to 5 = great gain.

IBL’s benefits for women are somewhat sustained: Grades after target course, by gender

IBL men: N=22-147; Non-IBL men: N=51-755. IBL women: N=8-57; Non-IBL women: N=29-322. Scale from 0.00 = F to 4.00 = A.
Summary of findings on IBL and gender

Self-reported learning gains - cognitive, affective, social - are lowest for non-IBL math-track women, are equal overall for IBL math-track men & women (IBL women write in more gains too). ∴ IBL levels the playing field for women in this class.

Attitudes (pre vs. post-course)
Confidence & motivation increase slightly for IBL women. Confidence, collaboration, use of effective learning strategies decline more noticeably for non-IBL women.

Later courses
IBL women’s gains are partially sustained. (∴ the playing field does not remain level)
Why?

Interview data: few gender differences at all. Others’ real performance becomes visible??

Older research: chilly classroom climate, dearth of women peers & role models

Recent research: stereotype threat is especially powerful for women and math

xkcd.com/385
Cognitive gains from survey, by achievement group

Non-IBL - Low: N = 16-18;  Medium: N = 52-54;  Top: 19-20.
IBL - Low: N = 44-45;  Medium: N = 161-162  Top: 81-82. Scale from 1 = no to 5 = great gain
Grade improvement (before/after course), by student prior GPA

IBL - Low: N= 7-49; Medium: N= 8-76; Top: N= 15-79. Scale from 0.00 = F to 4.00 = A

Course L1
Summary of findings on IBL and achievement

*Self-reported learning gains* - cognitive, affective, social - are *highest* for IBL low-achievers, especially for pre-service teachers. Also higher than non-IBL peers. No differences for higher-achieving students.

*LMT pre/post-test for pre-service teachers*
Low achievers make the *greatest score increases*.

*Later courses*
IBL low achievers’ grades *improve* while later grades decline for all others, IBL or non-IBL. (Low achievers do not take more courses)
No harm to high achievers (& they may take more courses)
Three claims about student outcomes

1. IBL instruction has positive outcomes for students
2. Especially women
3. And students with lower levels of prior achievement

Why do we think this is related to use of IBL methods?
Correlation of student learning gains with instruction

Student gains also correlate with observer ratings of interactions, atmosphere.
Take-home message

Changing *instructional activities* - how students meet the mathematics - toward more student-active approaches enhances student learning

Refining *practice of IBL methods* - everyday choices and acts of teaching - shapes & strengthens the key learning processes of engagement & collaboration
Conclusions

Patterns across multiple outcome measures are robust despite sizable & realistic variation:

IBL benefits students

IBL benefits women & boosts low-achieving students, with no harm to men or high achievers

Student outcomes are clearly linked to classroom use of active-learning approaches

Collaboration & deep engagement with mathematics are critical learning processes

Choose your practices to optimize & reinforce these!

www.colorado.edu/eer/research/steminquiry.html