Transforming Precalculus Instruction: Evidence-Based Course Design

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Abstract for DBER Group Discussion on 2015-04-09

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Title:
Transforming Precalculus Instruction: Evidence-Based Course Design

Abstract:
The UNL Mathematics Department has been focused on transforming precalculus instruction since 2012, with a goal of greater levels of student success. A short-term measure of student success is the passing rate (C or better), which has jumped from an average of 62% (2007-2011) to 80% for the past two falls. A longer-term measure of student success is recruiting and retaining undergraduates to STEM disciplines and careers. In this talk I will share specifics of the reform efforts (the who-what-when-where-why-and-how), and also share preliminary results from the research we have simultaneously been conducting into the reform efforts.
Transforming Precalculus Instruction: Evidenced Based Course Design

Wendy M. Smith
Center for Science, Mathematics and Computer Education
Presentation to the DBER Seminar, April 9, 2015

Freshman Math Courses
- Math 100A Intermediate Algebra (3 cr)
- Math 101 College Algebra (3 cr)
- Math 102 Trigonometry (2 cr)
- Math 103 College Algebra and Trigonometry (5 cr = 102 + 103)
- Math 104 Business Calculus (4 cr)
- Math 106 Calculus 1 (5 cr)
- Math 107 Calculus 2 (5 cr)

Next Steps
- Continue to collect data on course outcomes
- Begin to look at more longitudinal data (retention, course-taking patterns)
- Expand GTA training to LAs, tutors
- Scale up efforts to Calculus
- Scale up efforts to other math degrees in other universities (NSF is currently under review)

Support & Connections
- The project has test support from the Math Dept (through)
- Early support by SVCAA (space renovations, 25 GTA one semester)
- Grant from Association of Public and Land-grant Universities (APLU)
- MAA grant to fund learning assistants
- Mathematics Teacher Educator Partnership; one focus is active-learning mathematics
- Ongoing collaboration with UNCG, U of GA, and West Virginia University

Goals
- Math courses to be taught in smaller, more collaborative classes
- Students in calculus class must be comfortable with Math
- Increase in calculus that is comparable to Math
- Success in calculus is comparable to Math
- Increase in calculus that is comparable to Math
- Impact on student retention in calculus courses and students who enter directly from high school

Active Learning Mathematics
- Small group work & classroom norms engage students in sense-making activities
- Emphasize problem-solving habits of mind, mathematical thinking, solving problems, conjecturing, experimenting, exploring, analyzing, communicating reasoning
- Strategies:
  - Cooperative learning (group work)
  - In-class work sessions to allow for feedback, focus of group work on small math problems

Data Collection
- Instructor survey & interviews
- Student attitude survey proposal
- Student exam & course grades
- Student focus group interviews
- Interviews of involved faculty
- Analyze exams
- Observations (RTOP)
- Document GTA training & teaching seminar
- Document institutional change (efforts)
Transforming Precalculus Instruction: Evidenced Based Course Design

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Initial Goals:
- 75% success rate
- Success in calculus from both students transferring directly from high school

Current Goals:
- 80% success rate
- Improve student retention
- Success in calculus from both students transferring directly from high school

Data Sources:
- Instructor feedback
- Student assessment data
- Student exit interviews
- Student focus groups
- Interviews with faculty
- Analyze effectiveness of current instruction
Freshman Math Courses

- Math 100A Intermediate Algebra (3 cr)
- Math 101 College Algebra (3 cr)
- Math 102 Trigonometry (2 cr)
- Math 103 College Algebra and Trigonometry (5 cr = 101+102)
- Math 104 Business Calculus (4 cr)
- Math 106 Calculus 1 (5 cr)
- Math 107 Calculus 2 (4 cr)

Math Enrollment at UNL:
- 67% of freshmen enroll in a math course
- No other dept. garners more than 2% of freshmen
- Thus, Math is a huge factor in freshman retention

Course-Taking Patterns
- Math 100A
- Math 102
- Math 103
- Math 104
- Math 106
- Math 107

Precalculus Course Structure:
- Instruction is mostly grade-paced teaching assistants (STA) with a few adjunct instructors (often former ELR
school Math teachers)
- Common exams (with exams & final
- Math Resources Center: a tutoring room staffed by STAs
- Placement Exams
- Covers trigonometry, sin and cosine, parabolas, etc. Concepts place into one of the freshman courses

Success Rates:

<table>
<thead>
<tr>
<th>Course</th>
<th>Fall</th>
<th>Winter</th>
<th>Spring</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math 100A</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>Math 102</td>
<td>95</td>
<td>95</td>
<td>95</td>
<td>285</td>
</tr>
<tr>
<td>Math 103</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>270</td>
</tr>
<tr>
<td>Math 104</td>
<td>85</td>
<td>85</td>
<td>85</td>
<td>255</td>
</tr>
<tr>
<td>Math 106</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>240</td>
</tr>
<tr>
<td>Math 107</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>225</td>
</tr>
</tbody>
</table>
Math Enrollment at UNL

- 67% of freshman enroll in a math course
- No other dept garners more than 33% of freshmen (Music, Biology)
- Thus, Math is a huge factor in freshman retention
Course-Taking Patterns

Math 100A

Math 101

Math 102

Math 104
  business majors

Math 103

Math 106

Math 107
  200 level & higher
  (math, science, engineering majors)
Precalculus Course Structure

- Instructors are mostly graduate teaching assistants (GTA) with a few adjunct instructors (often former/current high school teachers)
- Common Exams (unit exams & final exams)
- Math Resource Center: a tutoring room staffed by GTAs
- Placement Exam
- Covering algebra, trigonometry, pre-calc concepts, place into one of the freshman courses
## Success Rates

<table>
<thead>
<tr>
<th>Course</th>
<th>Term</th>
<th>Enrollment</th>
<th>First-Time Freshmen</th>
<th>Sections</th>
<th>Success Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>College Algebra</td>
<td>Fall 2011</td>
<td>850</td>
<td>70.8%</td>
<td>29</td>
<td>64%</td>
</tr>
<tr>
<td>College Algebra</td>
<td>Spring 2012</td>
<td>560</td>
<td>1.4%</td>
<td>17</td>
<td>55%</td>
</tr>
<tr>
<td>College Algebra</td>
<td>Fall 2012</td>
<td>686</td>
<td>70.2%</td>
<td>25</td>
<td>59%</td>
</tr>
<tr>
<td>College Algebra</td>
<td>Spring 2013</td>
<td>458</td>
<td>3.9%</td>
<td>15</td>
<td>73%</td>
</tr>
<tr>
<td>College Algebra</td>
<td>Fall 2013</td>
<td>721</td>
<td>72.5%</td>
<td>26</td>
<td>81%</td>
</tr>
<tr>
<td>College Algebra</td>
<td>Spring 2014</td>
<td>407</td>
<td>2.7%</td>
<td>14</td>
<td>71%</td>
</tr>
<tr>
<td>Coll Alg &amp; Trig</td>
<td>Fall 2011</td>
<td>260</td>
<td>76.7%</td>
<td>9</td>
<td>68%</td>
</tr>
<tr>
<td>Coll Alg &amp; Trig</td>
<td>Fall 2012</td>
<td>277</td>
<td>85.6%</td>
<td>9</td>
<td>72%</td>
</tr>
<tr>
<td>Coll Alg &amp; Trig</td>
<td>Fall 2013</td>
<td>280</td>
<td>81.7%</td>
<td>9</td>
<td>76%</td>
</tr>
</tbody>
</table>

Note: College Algebra & Trig. spring enrollment tends to be ~75 students so success rate is extremely variable and thus not shown here.
Goals

Initial Goals

- 75% success rates – passing with a C or higher
- Success in calculus (106) at comparable levels from both students who enter from UNL precalculus courses and students who enter directly from high school

Current Goals

- 80% success rates
- Improve student attitudes toward mathematics
- Success in calculus (106) at comparable levels from both students who enter UNL precalculus courses and students who enter directly from high school
Data Collection

- Instructor survey & interviews
- Student attitude survey pre/post
- Student exam & course grades
- Student focus group interviews
- Interviews of involved faculty
- Analyze exams
- Observations (RTOP)
- Document GTA training & teaching seminar
- Document institutional change (efforts)
Lessons Learned

• Students need an incentive to complete pre/post surveys (complete during class; give quiz points)
Active Learning Mathematics

Goals:
- Teaching methods & classroom norms: engage students in sense-making activities
- Students develop habits of mind of mathematical thinkers: solve problems, conjecture, experiment, explore, create, communicate reasoning

Strategies:
- Cooperative learning (group work)
- In-class worksheets to direct focus of group work to meet math objectives
- Team quizzes
Problem 1 (Warm-up). Let $C(x) = 0.08x + 7.50$ be the cost of a road trip in dollars, where $x$ is the number of miles you travel. Give a possible interpretation for the slope and $y-$intercept.

Problem 2 (Warm-up, §2.1, #2). If $g(x) = x^2 - 5x + 6$, find $g(0)$ and solve $g(x) = 0$.

Problem 3 (Ex. 1). Let $f(t)$ be the total number of reported flu cases at UNL by the $t$th day of the semester. Answer the following with complete sentences.

What does $f(103)$ mean?
What does $f(50)$ mean?
What does $f(15) = 73$ mean?
Sample Team Quiz

Team Quiz 1: January 28, 2015

Names: ________________________________

Directions: You may work with the people at your table, but you must turn in team quizzes in groups of two or three. You may not use your notes, worksheets, or other resources on this team quiz.

Be sure to show work and/or explain your reasoning.

Problem 1. The following tables represent the relationship between the button number, $N$, that you push, and the snack, $S$, delivered by three different vending machines.

<table>
<thead>
<tr>
<th>Vending Machine #1</th>
<th>Vending Machine #2</th>
<th>Vending Machine #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$</td>
<td>$S$</td>
<td>$N$</td>
</tr>
<tr>
<td>1</td>
<td>M&amp;Ms</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>pretzels</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>dried fruit</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Hersheys</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>fat-free cookies</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>Snickers</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>fat-free cookies</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>Snickers</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>Snickers</td>
<td>9</td>
</tr>
</tbody>
</table>

a) To have a useful vending machine, must $S$ be a function of $N$ or $N$ a function of $S$? Explain.

b) For which vending machine(s) is $S$ a function of $N$?

c) For which vending machine(s) is $N$ not a function of $S$?
Close Coordination

Goals:
- Build out effective practices
- Have GTAs focus on students, not material

Strategies:
- Director of First Year Mathematics Programs Assistant conveners
- Common lesson plans
- Common exams
- Weekly coordination meetings
Sample Lesson Plan

Week 3: Section 2.1 *Input and Output* Math 101 Spring 2015

**Objectives (Students will be able to...):**

(i) Identify the input and output of a given function,
(ii) Evaluate a function to find an output value,
(iii) Solve an equation to find an input value,
(iv) Interpret input and output pairs as points on a graph.

**Relevant exercises & problems:** 3, 8, 13-14, 16b, 18-20-22-29-31

[5 min] Warm-up: Exercise 2, p. 72

Allow students to work alone or in groups. Go over answers on the board, highlighting the input/output pairs in each part.

[15 mins] Interpreting Inputs and Outputs

This problem incorporates a function given in words that does not have a formula. You may want to remind your students that this is still a valid function, and you will certainly want to model correct language for them. (That is, both write and say \( y = f(x) \).

(The following problem is on Worksheet 2.1.) Let \( f(t) \) be the total number of reported flu cases at UNL by the 4th day of the semester. Discuss the following questions with your class, asking them to explain with complete sentences. You may want to write these sentences on the board.

- What does \( f(10) \) mean?
- What does \( f(50) \) mean?
- What does \( f(15) = 75 \) mean?

Some questions to ask students in your discussion include: Is \( f(103) \) a function or a number? What does \( f(15) = 75 \) mean on a graph? Would we expect this function to be increasing or decreasing? (You may want to mention to your students that we will ask them to interpret functions in complete sentences on exams.)

[10 mins] Interpreting inputs and outputs for a function with a formula
Graduate Teaching Assistant Training

Goals:
- Teach GTAs elements of effective instruction
- Gain buy-in for Active Learning philosophy

Strategies:
- Pre-semester training workshop
- Year-long course for first-time GTAs
- Mentoring

Students in sections where the instructor was involved in the pedagogy course passed at higher rates

<table>
<thead>
<tr>
<th>Math II: Student Pass Rates by Instructor Involvement in Pedagogy Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructor Involvement in Pedagogy Course</td>
</tr>
<tr>
<td>GTAs not involved</td>
</tr>
<tr>
<td>GTAs involved</td>
</tr>
<tr>
<td>Instructor involved</td>
</tr>
</tbody>
</table>
Students in sections where the instructor was involved in the pedagogy course passed at higher rates

<table>
<thead>
<tr>
<th></th>
<th>In Pedagogy Course</th>
<th>Not In Pedagogy Course</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passed</td>
<td>299</td>
<td>127</td>
<td>426</td>
</tr>
<tr>
<td>Failed</td>
<td>64</td>
<td>43</td>
<td>107</td>
</tr>
<tr>
<td>Total</td>
<td>363</td>
<td>170</td>
<td>533</td>
</tr>
<tr>
<td>Pass Rate</td>
<td>82%</td>
<td>75%</td>
<td></td>
</tr>
</tbody>
</table>
First Year Mathematics Task Force

Goals:
  - Faculty support for high-quality GTA instruction
  - Maintain high standards for learning

Strategies:
  - Faculty mentor GTAs
  - Faculty review syllabi & exams for rigor, content, goals
Early Formative Assessment

Goals:
- Engage students at start of course
- Provide students opportunity to demonstrate mastery of prerequisite knowledge

Strategies:
- Prerequisite Mastery Activity-
  material a “B” high school Algebra 2 student would know & be able to do
The Prerequisite Mastery Activity was a strong predictor of student success. Students who passed the Prerequisite Mastery Activity passed both Exam 1 (upper left graph) and ultimately all the Exams (upper right graph) at statistically significantly higher rates than those who did not pass.
Learning Environment

Goal:
- Make group work easy and natural for students

Strategies:
- Classroom tables/chairs for group work
- Classroom whiteboard, document camera
- Extended time
  - Math 101: 150 to 225 min/wk
  - Math 103: 250 to 300 min/wk
“I love my group” “We’re teaching our groups, like to the people who don’t understand it.”
–Math 103 students
“We run into problems that individually we would probably get stuck on, but instead of working it out of the books ourselves or trying to get lined up with the professor, we can group together and try and get it done. We’ve even gone as far as get together to get the homework done and branching out into other problems and not just the team quiz.”

-Math 101 Student
Students in sections held in Brace labs (renovated rooms) passed at higher rates than sections in other rooms.

<table>
<thead>
<tr>
<th></th>
<th>In Brace Labs</th>
<th>Not In Brace Labs</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passed</td>
<td>416</td>
<td>39</td>
<td>455</td>
</tr>
<tr>
<td>Failed</td>
<td>98</td>
<td>13</td>
<td>111</td>
</tr>
<tr>
<td>Total</td>
<td>514</td>
<td>52</td>
<td>566</td>
</tr>
<tr>
<td>Pass Rate</td>
<td>81%</td>
<td>75%</td>
<td></td>
</tr>
</tbody>
</table>
Learning Assistants

Goal:
• Support group work & student engagement

Strategies:
• Hire undergraduates to assist with course instruction
• Recruit from majors, “A” students
• Can support larger class sizes
Students in sections with a Learning Assistant passed at higher rates than sections without a learning assistant.

### Math 101 Student

#### Pass Rates by LA Use

<table>
<thead>
<tr>
<th></th>
<th>LA</th>
<th>No LA</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passed</td>
<td>335</td>
<td>120</td>
<td>455</td>
</tr>
<tr>
<td>Failed</td>
<td>76</td>
<td>35</td>
<td>111</td>
</tr>
<tr>
<td>Total</td>
<td>411</td>
<td>155</td>
<td>566</td>
</tr>
</tbody>
</table>

Pass Rate 82% 77%
Support & Connections

- The project has had support from the Math Dept throughout
- Early support by SVCAA (Brace renovations, .25 GTA one semester)
- Grant from Association of Public and Land-grant Universities (APLU)
- MAA grant to fund learning assistants
- Mathematics Teacher Education Partnership: one focus is active learning mathematics
- Ongoing collaboration with UNO, U of Colorado Boulder, Auburn, U of West Virginia
Next Steps

- Continue to collect data on course outcomes
- Begin to look at more longitudinal data (retention, course-taking patterns)
- Expand GTA training to LAs, tutors
- Expand efforts to Calculus
- Scale up efforts to other math depts in other universities (I-USE proposal to NSF is currently under review)
Thanks go to the APLU and MAA for grants that have partially supported this work, as well as the UNL Math Dept which has committed to evidence-based course design. Thanks go to the First Year Mathematics Task Force, which has supported the changes, mentored GTAs, and reviewed exams. Thanks especially to those on the research team, including Dr. Allan Donsig, Dr. Nathan Wakefield, Molly Williams, Jessalyn Bolkema, Doug Dailey, Lauren Keough, Nick Owad, and Lixin Ren.

Questions?