Improving Student Interest, Mathematical Skills, and Future Success through Implementation of Novel Mathematics Bridge Course for High School Seniors and Post-secondary Students

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Abstract
We present a new course titled "Introduction to the Mathematical Sciences." The course content is 1/3 algebra, 1/3 statistics, and 1/3 computer science and is taught in a laboratory environment on computers. The course pedagogy departs radically from traditional mathematics courses taught in the U.S. and makes extensive use of spreadsheet software to teach algebraic and statistical concepts. The course is currently offered in area high schools and two-year post-secondary institutions with financial support from a Blandin Foundation grant (referenced under BFG). We will present empirical evidence that indicates students in this course learn more algebra than students in a traditional semester-long algebra course. Additionally, we present empirical evidence that students learn statistical and computer science topics in addition to algebra. We will also present the model of developing this course which depended on increasing future student success in a variety of disciplines at the post-secondary level of study.

Introduction

Schools in the United States have been unsuccessfully trying to address two major problems in mathematics education: a lack of interest in the mathematical sciences by students who become worse as they progress through the grade levels *and* students choosing to not take any mathematics classes in 11th or 12th grade or only taking mathematics classes that satisfy requirements but do not help them to be successful in post-secondary education. These two problems are exacerbated by the fact that most high school mathematics curricula in the U.S. are based on what we call the *calculus model* which is four years of curriculum culminating in an advanced placement (AP) calculus course. The measure of success for this model is the AP calculus success rate and the number of students in the high school taking AP calculus. The problem is that only approximately 10% of a given high school has students ready and capable of taking AP calculus their senior year. The rest of the students (90%) may suffer from the *calculus model* by virtue of their exclusion. Problems with the post-secondary model of mathematics education also created a strong need for developing this course. Over a five year period (2001-2006), Glen Richgels examined Bemidji State University (note that BSU is a medium size liberal arts university typical of many post-secondary institutions across the U.S.) data and discovered that approximately 78% of all graduates across all programs need one or more statistics courses to graduate, just 12% need one or more calculus courses. The *calculus model* in high school is not benefiting most students at college.

With these problems in mind, during the spring of 2007, faculty at BSU (four from mathematics: Todd Frauenholtz, Ann Hougen, Ryan Hutchinson, Glen Richgels, one from statistics: Derek Webb, and one from computer science: Marty Wolf) created and piloted a novel new course titled "Introduction to the Mathematical Sciences."

Creation and Content of the Course

The creation of our course occurred in the winter of 2007. The course was experimentally taught at BSU in the spring of 2007 and simultaneously at Lincoln High School in Thief River Falls, Minnesota. The initial experimental offering of the course at BSU in the spring of 2007 was supported by a Minnesota State Colleges and Universities grant (referenced under IPESL).

Choosing course content was novel compared to how most mathematical sciences courses are created. Course content focused on three areas of mathematical science: algebra, basic statistics, and basic computer science. Topics for the course were chosen based on their usefulness and applicability in various fields of study outside the discipline of mathematics that students may pursue at the post-secondary level. Our overarching goal was to populate our course with topics that would contribute to student success at the post-secondary level in a wide range of programs of study.

Topic choices were based on over 20 interviews of faculty at BSU in many different programs. Examples of the diverse programs from which faculty were interviewed include: political science, psychology, theatre, geology, physics, applied engineering and business administration. The following table contains topics included in the course.

Algebra Topics	Statistics Topics	Computer Science Topics

Functions
• Represented by formula, table, graph, words
Graphical and Tabular Analysis
• Tables and trends
• Graphs
• Solving linear equations
• Solving nonlinear equations
• Optimization
Linear Functions
• The geometry of lines
    • Linear Functions
    • Modeling data with linear functions
    • Linear regression
    • System of equations
	Collecting and displaying data
	• Types of data
	• Creating data files in spread sheets
	• Displaying data in tabular format
	• Bar charts, histograms, pie charts, box plots, scatter plots
	Populations and samples
	Measures of central tendency
	• Sample mean, median, and mode
	Measures of dispersion
	• Sample range, standard deviation, and inter
		Syntax and Semantics
		Understanding Processes
		• Describing processes used to solve specific problem
		• Generalizing processes to solve general problem
		• Converting processes into computer solutions
		The notion of a "variable" in computing
		• Variable names, references, and values
		Formulas and expressions
		• Operations, evaluation order, results, and errors
		Making decisions
		• Logical and rational operators and their values

Rates of Change • Velocity • Rates of change of other functions	quartile range Shapes of distributions • Skewness, symmetry, and modality Correlation and association Introduction to linear regression	• Conditional syntax • Conditional semantics Using functions • Function syntax and semantics.

Pedagogy and Learning Environment of the Course

The pedagogy and learning environment of the mathematics and statistics portions of the course are in alignment with the National Council of Teachers of Mathematics (referenced under NCTM) recommendations. The pedagogy and learning environment consist of the following components:

- Algebra, statistics and computer science topics are all presented in the context of real-world problems taken from many disciplines. This is especially critical in the teaching of algebra topics. In our class, algebra is not taught as a set of rules and symbol manipulation skills, which is what students typically see in traditional algebra classes. Students readily see the applicability of the algebra topics they are studying.
- Algebra, statistics, and computer science topics are interwoven and not taught in isolation. Our course content is not three topics taught separately. Rather, it is three topics taught in concert making use of natural relationships. Students understand how the "mathematical sciences" is a cohesive discipline, not silos of information.
- Most algebra, statistics, and computer science topics are taught using spreadsheets. Students are much more engaged in the learning of algebra topics using spreadsheets and they also have a much better understanding of, and need for, proper order of operation and algebraic syntax.
- Students spend at least half their class time in a computer laboratory environment. This pedagogical aspect of the course depends on the available facilities the school. If possible, we prefer that the course be taught entirely in a computer laboratory environment. If not, students should spend at least 50% of classroom time in a computer laboratory.
- The classroom time commitment for this class is approximately double that of a typical three credit college algebra course. This is very important because it allows enough classroom time for students to work together on their own, in student groups, and with the instructor to complete the majority of their "homework." That way, they know they are being successful and do not struggle in isolation at home. This ensures that the majority of work is completed and students remain engaged in learning.

Initial Implementation and Expansion

In the spring of 2007 the course was piloted at BSU and at Lincoln High School. Afterwards, adjustments and improvements were made. One adjustment was to add content to the course when offered at high schools because high schools usually have many more course contact hours than colleges or universities. The course was then offered at BSU in the fall of 2007 and at two high schools: Bemidji High School and Lincoln High School. Bemidji State University continues to offer the course once per year and has accepted the course into the university's permanent curricular offerings.

In the fall of 2008 Derek Webb and Glen Richgels were awarded a large grant from the Blandin Foundation to offer the course in multiple high schools and post-secondary institutions (referenced under BFG). The map below shows all partnering schools where the course is being offered. The institutions are color-coded in the following way:
Red: post-secondary institutions offering the course starting in the spring of 2009 – Northwest Technical College in Bemidji; Northland Community College in Thief River Falls, Red Lake Nation College in Red Lake and White Earth Tribal and Community College.
Blue: high schools offering the course starting in the spring of 2009 – Lincoln HS, Bemidji HS, Red Lake HS, and Win-E-Mac HS.
Purple: post-secondary institutions offering the course starting in the fall of 2009 – Leach Lake Tribal College and Fond du Lac Tribal and Community College.
Green: high schools offering the course starting in the fall of 2009 – Clearbrook-Gonvick H S, Grand Rapids HS, Floodwood HS, Cass Lake HS, and Walker-Hackensack-Akeley HS.

Empirical Evidence of Success
Assessment instruments were used to assess content knowledge gained during the course. A standard placement test was used to assess algebra knowledge. This placement test has been routinely used by various universities in Minnesota to place students into their initial collegiate mathematics course, including various algebra courses. The test was given at

the beginning of the semester and again at the end. Statistics and computer science tests were also created and were given at the beginning and at the end of the semester. Appropriate and consistent pre-test and post-test assessment protocol was followed at all institutions every time the course was assessed.

During the spring semester of 2007, one traditional college algebra class and two liberal education mathematics classes were also studied as control groups. Students in each of these classes were given the same standard placement test (pre and post) to assess algebra knowledge gains throughout the semester. These students were not given the statistics or computer science tests because these topics were not covered in the algebra classes. In the liberal education mathematics class, statistics was only briefly discussed and computer science was not discussed at all. The pre-test and post-test results were analyzed using paired *t* tests. Significant increases in post-test scores vs. pre-test scores were found in the placement (n = 14, p-value = 0.010), statistics (n = 17, p-value = 0.000), and computer science (n = 17, 0.000) tests for our experimental course. Interestingly, no significant increase was found in the placement test for the students in the traditional college algebra class (n = 16, p-value = 0.308) or in the liberal education classes (n = 9, p-value = 0.087 and (n = 13, p-value = 0.151).

The course was again taught at BSU in the fall of 2007 and is being taught in the spring of 2009. The course was piloted at Lincoln High School in the spring of 2007 and again in the spring of 2008. The course was piloted at Bemidji High School in the fall of 2007 and again in the fall of 2008. The pre-test and post-test assessment data are presented below. Note that for some institutions, the statistics and computer science (CS) pre-tests and post-tests were combined so only one result is given. This was due to how the test results were compiled by the individual instructors at the partnering institutions.

<table>
<tr><td>Institution</td><td>Placement Test</td><td>Statistics Test</td><td>CS Test</td></tr>
<tr><td>BSU – fall 2007</td><td>n = 15, p = 0.218</td><td>n = 14, p = 0.013</td><td>n = 14, p = 0.000</td></tr>
<tr><td>Bemidji HS – fall 2007</td><td>n = 11, p = 0.008</td><td colspan="2">n = 11, p = 0.000</td></tr>
<tr><td>Bemidji HS – fall 2008</td><td>n = 22, p = 0.000</td><td colspan="2">n = 22, p = 0.000</td></tr>
<tr><td>Lincoln HS – spring 2007</td><td>n = 12, p = 0.263</td><td colspan="2">n = 12, p = 0.000</td></tr>
<tr><td>Lincoln HS – spring 2008</td><td>n = 22, p = 0.019</td><td colspan="2">n = 22, p = 0.000</td></tr>
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Based on the placement exam pre-test and post-test results, the algebra knowledge gains of students in our class are not consistently statistically significant. There are two classes that had no statistically significant gain. The reason why most classes showed gains in algebra and two did not is not known and is a focus of ongoing research. There has been consistent statistical evidence of statistics and computer science knowledge gains in all the classes offered to date. This is a very positive result and a strong point of the course because, not only are the statistics and computer science topics engaging to most students, students are also increasing their content knowledge in these areas of mathematical science.

Summary

Most high school math curricula in the U.S. are based on what we call the *calculus model* which is four years of curriculum culminating in an advanced placement (AP) calculus course. We have developed a novel mathematical sciences class that we believe is a more appropriate and valuable alternative to the *calculus model* for many students in the U.S. in 11^{th} and 12^{th} grades. The course pedagogy was developed based on sound mathematics and statistics education research and the course content was created based on content needs in a variety of disciplines. The content is interwoven and consists of topics from algebra, statistics, and computer science. The content is largely delivered through projects and investigations that create and hold student interest and promote learning.

The course was piloted at Bemidji State University and two area high schools and by the end of 2009 will be offered in approximately 15 high schools and post-secondary institutions.

Through our research and the process of creating the course, we believe course content and pedagogy for mathematical sciences and, specifically, mathematics courses that have wide student exposure should be developed with input from many areas of study, not just from pure mathematicians. We believe this improves the pedagogy of courses and the content of courses focuses on relevant topics, not purely theoretical topics or topics for which students do not see any applicability. Too many mathematics courses in the U.S. remain unchanged through many years and are out of alignment with current mathematics education research and findings.

References

BFG – The Blandin Foundation awarded $225,000 in support of the Northern Minnesota College Readiness Partnership Grant to the MnSCU Foundation in September, 2008. This is a regional initiative designed to improve student success and build capacity among local school districts and community colleges to sustain positive long-term results. Resources will be provided to implement an activities-based mathematics course and to conduct research to determine best practices to better serve students of color, low-income status or who require nontraditional approaches to mathematics education.

IPESL – Initiative to Promote Excellence in Student Learning grant program through the Minnesota State Colleges and Universities awarded authors $63,374 grant. Title of project: Building Student Success on a Foundation of Preparedness. Grant awarded in November, 2006.

NCTM – Principles and Standards for School Mathematics, published by the National Council of Teachers of Mathematics, 2000.