A Capstone Course to Improve the Preparation of Mathematics Teachers on the Integration of Technology

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***Abstract**. A decade after the first set of NCTM standards were published, and when a large percentage of USA secondary students were using graphing calculators in the mathematics classroom, we began to study the degree of readiness of pre- and in-service mathematics teachers in two key areas. First of all, to what extent were they prepared to use research-proven teaching and learning approaches recommended by the standards? Concretely, had these future math teachers being properly exposed to inquiry-based teaching and learning, to team work, and to exploration and discovery? Secondly, besides learning how to use graphing calculators, were these students ready to properly integrate this technology in the teaching and learning of mathematics? Our initial research pointed to a weak theoretical exposure with very little or no practices whatsoever conducing to the internalization of the approaches aforementioned. On the other hand, most students knew how to use the very basic functions of a graphing calculator, but could not use numerical and graphical techniques, let alone any of the new mixed techniques, to solve problems. Further research indicated that they lacked the basic conceptual understanding that the exposure to proper integration of technology promotes. Unaware of any existing course or textbook focusing on the problems outlined, we developed a capstone course aiming to address these deficiencies. In this presentation we will review the mathematical content, technology, teaching tools, strategies, and type of assessments used. In addition, quantitative and qualitative evaluation on the results of this course will be presented.*

Introduction

The publication of the initial set of mathematics standards (NCTM, 1989, 2000)), where it was unambiguously declared that technology is essential in teaching and learning mathematics, since it influences the content taught while enhancing students' learning, coincided with the availability of hand-held graphing technology (HHGT), such as the Casio 7000 and the TI-81, that eliminated the need for computers and very costly software at the time, facilitating the implementation of technology at the secondary and college levels. The initial large scale research at the pre-calculus level (Quesada & Maxwell, 1994) showed that proper integration of HHGT yielded positive significant results on overall students' performance. A comprehensive review of the research on HHGT at the secondary level (Burril, Allison, Breaux, Kasberg, Leatham, & Sánchez, 2002) pointed to improved conceptual understanding when the curricula is designed to take advantage of the HHGT. In addition to the integration of technology in the curricula, the more time students spend using the technology and the teacher professional development were factors that contribute to the students obtaining significantly higher scores (Hellen Research Associates, 2005).

In 1997, the College Entrance Examination Board in the USA approved the use of any HHGT without QWERTY keyboard for the SAT test. As a result, there was an increasing demand in the USA on in-service teacher training on the integration of technology in the mathematics classroom.

Factors That Motivated the Creation of the Course

What we learned from the analysis of tests and surveys administered in the workshops for in-service teachers that we offered for two decades, since 1992, (Quesada, A. & Dunlap L, 2011), (Dunlap L. & Quesada, 2009, 2012) , as well as from the preparation of pre-service teachers and incoming college students (Quesada A. & Renker R, 2008), made clear, from the beginning, the magnitude of the challenge that the proper integration of technology and teaching techniques with proven research results posed at the time and to some extent still does. Some of the major misconceptions and lack of knowledge observed included:

1. The belief that teaching or learning the basic features of the calculator is all that is needed to properly integrate technology.
2. Many students did not learn the basic shape and properties of the parent functions of the families of continuous functions nor how to sketch the graph of any other member of the family obtained via plane transformations.
3. Most students were not exposed to the relative growth within and between the different families of continuous functions.
4. Most students had not been exposed to:
    a. the local versus end behavior of functions,
    b. the parity of the asymptotes of rational functions,
    c. the parity of the zeroes of algebraic functions,
    d. the number of possible turning points of a polynomial of degree *n*.
5. Very little use of numerical calculations to determine roots or to analyze the relative position of graphs.
6. As a consequence of points 2-5, it came as no surprise to learn that the only strategy of many students to look for the complete graph of a function was to zoom out or in.
7. Most students have not been prepared to estimate numerically or to sketch the graph of a function; rather they tend to use continuously the calculator.
8. One might have thought that since the row-echelon form and the reduced-row-echelon form of a matrix was readily available in the graphing calculators, students would have been exposed to the row elimination process to solve systems of linear equations since it always yields the correct answer, but this was not the case for most students. Moreover, seldom we found students familiar with any of the matrix applications (Networks, plane transformations, cryptography …) that began to appear in the new curricula.
9. More students were coming with a brief introduction to regression than to many of the previous topics; however, most of them have used only some of the basic models, with little conceptual understanding of the process or to what type of data was a model more appropriate to be used with.
10. Very few teachers had even heard of some of the new approaches to modeling and problem solving made possible by HHGT and dynamic geometry software (Quesada A. & Edward M., 2008).

11. Students have not been exposed to technology pitfalls like the discrete nature of the graphs, or the graphing difficulties encountered when the precision of the machine was exceeded. As a result they trusted blindly the technology.
12. Most of the pre-service teachers we met in math courses have heard about the positive results that researchers in mathematics education have found on the use of inquiry, teamwork, and metacognition, but they have not experienced any of these techniques as students.

The situation was not much different among in-service teachers who have had a half-day or full day workshops. We realized that those whose education never included the use of HHGT, have learned to think mostly algebraically, and that they needed to be exposed for a longer period of time to the Rule of Three in order to develop the ability to automatically move comfortably among the algebraic, graphical, and numerical representations.

During the nineties', new experimental textbooks and curricula (Core Plus, 1998), (The North Carolina School of Science and Mathematics, 1996), (The University of Chicago School Mathematics Project, 1992) appeared, mostly for the secondary level, that fostered the integration of technology and had excellent new content and applications as well as pedagogical approaches that emphasize discovery via inquiry-based activities. However, an analysis of twelve Pre-calculus textbooks, published from 2000-2006, for college students, including several of the best sellers, found a lack of uniformity on the way the new topics were addressed. While some of the textbooks gave prominence to a particular new topic or approach, others chose to address that topic at the end of a section's homework or to no address it at all. It is not surprising that an analysis of three groups of pre-service teachers from three well-known universities in the Midwest, and of a large group of in-service teachers' performance on a pretest consisting of questions on an established set of relevant topics that technology facilitates, found similar results to the textbooks evaluation on the same topics (Quesada A. & Renker R, 2008).

The Capstone Course

Unaware of any existing course or textbook focusing in the problems outlined to prepared secondary teachers, in 2002 we developed a capstone course for pre-service teachers aiming to address not only the deficiencies found on the proper integration of HHGT, but also their lack of familiarity with teaching techniques with proven research results.

From the beginning the course was a work in progress. It should address not only existing but also incoming relevant technologies as well as new research-proven methodologies, to enhance the teaching and learning of mathematics. Initially, the course needed to take under consideration that most pre-service students have not been exposed to the integration of technology, and to the fact that the new methods for the most part have not been modeled in their classes by their professors at any level. Hence, it should provide enough practice conducing to the internalization of these approaches. Progressively, the course should adapt to the ongoing implementation of these ideas on secondary schools and college, and to include incoming new changes. Thus, while initially students used the TI-84 and TI-voyage calculators together with Cabri and Excel, in the last few years they have used the TI-Nspire that make possible to work with graphs, dynamic geometry software, CAS, and a spreadsheet, with the added advantage of being able to recognize a variable defined in one of these platforms, in any of the other ones. The existence of these platforms not only facilitates exposing the students to multiple representations, but also provide for new problem solving approaches (Quesada & Edwards, 2008).

Course Goals

The present goals established for this course are consistent with its underlying philosophy:

1. The course aims to prepare secondary teachers, teaching assistants, and students interested in teaching mathematics with the appropriate working knowledge on “the use and integration” of existing and incoming relevant technologies in the teaching and learning of mathematics. We expect to address the use of the following tools: elementary, graphing, and symbolic (CAS) calculators, dynamic geometry software, Learning Management System, mathematical word processing, and distance learning.
2. To prepare future teachers to develop a balanced approach to the use of technology. The Rule of Four (algebraic, numerical, graphical, & verbal) is used throughout the course.
3. To help future teachers to increase their students' problem-solving capabilities via the use of multiple representations, inquiry-based (IB) approach, and participation in individual and team projects that incorporate investigation and the use of technology. The course aims to facilitate that pre-service teachers do experience inquiry by solving IB activities weekly as students, and by developing some activities under this modality as teachers. In addition, teamwork is required, thus participants work as members of different teams that communicate in person or via Springboard, a Learning Management System (LMS) currently used. Finally, to convey the fact that technology empowers student to do research at the secondary and undergraduate levels (Quesada, 2001 & 2010), participants face exploration and discovery activities throughout the semester and are asked to include extension questions of this nature in every activity they develop.
4. The TI-Nspire CAS calculator and software (that includes the traditional capabilities of a graphing calculator together with dynamic geometry software, a spreadsheet, and a computer algebra system), is regularly used in class.
5. To increase students' technical communication skills by requiring written projects using Word with Mathtype and oral presentations.

Course Content

Likewise, the course content was chosen taking into consideration the results at the different levels of our initial research, namely, the absence of basic tools and of conceptual understanding that the continue exposure to proper integration of technology promotes. Hence we decided to look in depth at all the key mathematical topics that secondary teachers must be prepared to teach using numerical and graphical techniques, and the different data types (table, lists, sequences, matrices…) that recent HHGT provides, the new topics now available (linear and nonlinear regression models, matrix applications…), as well as the new mixed techniques to problem solving (Quesada, 2011). Especial emphasis was given to topics foundational to Calculus at the secondary level (Quesada, 2007), to research-proven approaches to important concepts (Quesada, Einsporn & Wiggins, 2008), and to tools, like recursion, that can be used across the curriculum (Quesada, 2012).

The content of the course has not evolved much in the last decade:

1. The role of technology to foster understanding, intuition, and discovery through investigation. Risks, errors, limitations of technology.
2. The use of graphical, numerical, and algebraic methods (via technology) to study:

   i.) Algebraic and transcendental families of functions. Plane Transformations.

   ii.) Systems of equations and inequalities of linear and non-linear functions.

   iii.) Data Analysis: Linear & non-linear models of regression.

   iv.) Matrix applications (Markov Chains, Plane Transformations, Cryptography, Leslie model, Graphs...)

   v.) Iteration and Recursion.

   vi.) Multiple representations. Parametrics. Lists.
3. On problem solving, extensions, and applications. New approaches to problem solving.
4. Introduction to Symbolic Manipulators (CAS), and their use in Algebra, Calculus, and Linear Algebra.
5. Connecting mathematics to the physical world.
6. Interactive Geometry (Dynamic geometry software). Connecting Geometry, Algebra, and Calculus.
7. Implications of the use of technology in methods and assessment.

All the course materials, general information, content, assignments, grades, and deadlines are available on Springboard. The syllabus includes the following disclaimer. Due to the dynamic nature of this course, which is technology-dependent, the content described may prove to be too ambitious and adjustments may be needed.

Course Assessment

The assessment of the course has different components. In addition to the traditional individual assessments of tests and quizzes that always include some questions from the assigned homework and labs, there are team assessment for the weekly inquiry-based activities, in class presentations and the final project. Since most of the students taking the class, graduate and start teaching by the following academic year, we wanted them to a) have their course work digitally available in the future, to be used as a possible resource in their own classes, b) to use metacognition on their learning by reflecting weekly on concepts, properties, and methods learned together with their own insights, c) to observe their changes during the semester via an initial and final statement on their position on the use of technology, d) to keep any additional relevant reading, *related information* found in their process of preparing for this course, and e) to learn from their own errors by correcting their tests and quizzes. To that end, we require an e-portfolio, a course component described in the course syllabus as follows:

Student will prepare an e- *portfolio* that showcases their work during the semester. It must include:

a) their *initial position statement* on the use of technology in the teaching and learning of mathematics in the classroom,

b) the completed weekly *homework*, typed or handwritten and scanned,

c) optional: the completed daily *notes,*

d) the *final project,*

e) clearly corrected (with corrections in bold or in different color) *quizzes, tests*, and *labs,*

f) a *weekly reflection* on: concepts, properties, and methods learned during the week, and any personal ideas on teaching them,

g) optional: any *special project*, *in-class presentations*, *articles* or *papers read* on the subject (web-based or print) with a brief synopsis of their contents, additional *related information* (on content or methodology) collected,

h) a *final statement* at the end of the semester about the role of technology in the teaching and learning of mathematics should be included,

i) an index is required. You are encouraged to use web sites to help develop your portfolio!

j) the portfolio will be assessed on content, completeness, correctness, and presentation (organization, clarity ...).

The syllabus describes the *final project* as follows: Teams of students will work together to present a topic selected from the list of suggested topics provided in class. A team may also select and research its own topic with approval from the professor. A draft on the content of the selected topic must be submitted the ninth week. Beginning the 13th week, each team must be prepared to present their topic in class. This presentation will consists of an overview of your topic (preferably using power point), and an inquiry-based lesson containing several IB-activities. The complete set of the IB-activities developed during the semester, of publishable quality, will be submitted. If selected by the Akron Math Community editorial committee the activities will be posted on the web.

Conclusion

Although in the USA there is no centralized ministry of education, most high schools paid attention to the NCTM recommendations as illustrated by the fact that in 2004 it was estimated that 80%-85% of secondary students in USA were using HHGT. However, as depicted by the "math wars," at the college level there was no consensus whatsoever. Thus, while some colleges adopted the new ideas on integration of technology, others rejected its use, and many others let the instructors make their own decisions. A reflection of this situation was the unresolved conflict between adding new relevant ideas to the curriculum that HHGT makes possible and the need for eliminating some of the traditional material that becomes less relevant, hence the length of most of the pre-calculus textbooks considered nearing 800 pages for a one semester course.

It is important to mention that most Ph. D's in content disciplines are not required to take any methods course. In addition, mathematics journals do not include articles in mathematics education. Hence, there is no process formally established to inform those teaching at the college level of important research results to improve the teaching and learning of mathematics. Thus, a college professor may have never been exposed to or have read anything about some research-proven techniques to enhance mathematics teaching.

As mentioned before, ever since the course was offered for the first time in 2002, the pre-service students have taken a pre- and post-test consisting of questions on an established set of relevant topics that technology facilitates. It is the same test that we later start offering to in-service teachers. The results up to the last workshop we offered on the spring-summer of 2009 have been quite similar; the average in the pretest for pre-service teachers is 44.5%, while the median for the in-service teachers is 46.2%. The average of the posttests after the treatment increased to 77% and 75% respectively. Also, at the beginning and end of each class and workshop, the pre- and in-service teachers responded to survey questions that related integrating technology with a variety of content. The focus for the pre-service teachers was their knowledge of how to do this and the focus for the in-service teachers was how often they taught this way. The results also increased significantly after the treatment (Quesada & Dunlap, 2011). All these results leave little doubt on the ongoing need for this kind of training.

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