The Journal of Mathematics and Science:

COLLABORATIVE EXPLORATIONS

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PART I: SPECIAL ISSUE

A National Consortium for Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnerships (SUMMIT-P)

PART II: REGULAR JOURNAL FEATURES

Virginia Mathematics and Science Coalition

JOURNAL OF MATHEMATICS AND SCIENCE: COLLABORATIVE EXPLORATIONS

The *Journal of Mathematics and Science: Collaborative Explorations* is the official journal of the Virginia Mathematics and Science Coalition (https://www.vamsc.org/), a non-profit organization comprised of education, scientific, corporate, and public policy leaders committed to the sustained elevation of mathematics and science education to ensure that all Virginia's students and citizens have the foundation required for life-long success in their daily lives, careers, and society.

AIMS AND SCOPE

The *Journal of Mathematics and Science: Collaborative Explorations* is a forum which focuses on the exchange of ideas, primarily among higher education faculty from mathematics, science, and education, while also incorporating the perspectives of elementary and secondary school teachers. Articles are solicited that address the preparation of prospective teachers of mathematics and science in grades K–12, the preparation of mathematics and science teacher leaders for grades K–12, and innovative programs for undergraduate STEM majors.

Articles are solicited in the following areas:

- all aspects of undergraduate STEM education with particular interest in activities that will provide new insights in mathematics and science education
- all aspects of the preparation of mathematics and science teacher leaders and their work in K–12 schools and school districts
- reports on new curricular development and adaptations of "best practices" in new situations with particular interest in interdisciplinary approaches
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SUMMIT-P SPECIAL ISSUE EDITORIAL BOARD

The Editorial Board encouraged SUMMIT-P participants to report on their work and promoted discussion of collaboration among faculty from a variety of disciplines and different institutions. The board provided feedback on draft papers before the individual papers were submitted to the Journal of Mathematics and Science: Collaborative Explorations for external review.

Journal of Mathematics and Science: Collaborative Explorations

Volume 18

Part I: Special Issue

A National Consortium for Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnerships (SUMMIT-P)

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Part II: Regular Journal Features

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INTERDISCIPLINARY COLLABORATION TO DEVELOP MEANINGFUL MATHEMATICAL EXPERIENCES

Susan L. Ganter
The University of Texas Permian Basin
susan.ganter@utpb.edu

William Haver
Virginia Commonwealth University
whaver@vcu.edu

https://doi.org/10.25891/bhb6-9847

ABSTRACT

This issue of the Journal of Mathematics and Science: Collaborative Explorations (JMSCE) is the second special volume highlighting the impact of the consortium for Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnerships (SUMMIT-P). The development and goals of SUMMIT-P were outlined in the preface of the first special issue of JMSCE devoted to this project (Ganter & Haver, 2020). Full participation from partner discipline faculty is key to the success of redeveloping introductory mathematics courses in a way that incorporates the contextual needs of the other disciplines. As such, SUMMIT-P's first task was to find ways to best engage colleagues in the partner disciplines. The first special volume's preface detailed these recommendations. The seven papers in this second special issue, written two years later in the cycle of the project, describe how the collaborations evolved under specific institutional circumstances while also describing the outcomes and products of the collaboration. The papers also focus on the processes used to support and promote successful interdisciplinary collaboration, including the use of: fishbowl discussions to enable mathematics faculty to understand the perspectives of faculty in partner disciplines; site visits to strengthen collaboration among faculty from different disciplines and different institutions; collaboration protocols to provide a structured format for discussions; faculty learning communities to develop ongoing institutional structures for collaboration; and assessment and evaluation measures to provide a long-term overview of impact at all levels.

KEYWORDS

interdisciplinary collaboration, MAA/CRAFTY, Curriculum Foundations, SUMMIT-P

This issue of the *Journal of Mathematics and Science: Collaborative Explorations* (JMSCE) is the second special volume highlighting the impact of the consortium for Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnerships (SUMMIT-P). Specifically, the seven papers in this issue describe collaborations among mathematicians and faculty from partner disciplines that were developed as a part of the SUMMIT-P work. The development and goals of SUMMIT-P were outlined in the preface of the first special issue of JMSCE devoted to this project (Ganter & Haver, 2020).

The Curriculum Foundations (CF) project of the Curriculum Renewal Across the First Two Years (CRAFTY), a committee of the Mathematical Association of America, featured 22 multi-day disciplinary workshops, each consisting of roughly 20 partner discipline (e.g. engineering, sociology, business, etc.) participants and 10 mathematicians (Ganter & Barker, 2004; Ganter & Haver, 2011). For each workshop, the partner discipline faculty produced a report focused on the mathematical needs of students in their discipline. The same message was repeated in the reports again and again: introductory collegiate mathematics courses should provide students with an appreciation and understanding of fundamental mathematical topics while grounding the discussion in a variety of contexts. SUMMIT-P was formed as a response to the work initiated through CF.

Full participation from partner discipline faculty is key to the success of redeveloping introductory mathematics courses in a way that incorporates the contextual needs of the other disciplines. As such, SUMMIT-P's first task was to find ways to best engage colleagues in the partner disciplines. The first special volume's preface detailed these recommendations and described the specific strategies undertaken by the original 12 SUMMIT-P institutions in response to the CF findings.

The papers in this second special issue, written two years later in the cycle of the project, describe how the collaborations evolved under specific institutional circumstances while also describing the outcomes and products of the collaboration. The papers also focus on the processes used to support and promote successful interdisciplinary collaboration, including the use of:

- **fishbowl discussions** to enable mathematics faculty to understand the perspectives of faculty in partner disciplines;
- **site visits** to strengthen collaboration among faculty from different disciplines and different institutions
- **collaboration protocols** to provide a structured format for discussions;
- **faculty learning communities** to develop ongoing institutional structures for collaboration;
- **assessment and evaluation measures** to provide a long-term overview of impact at all levels.

Each of the seven papers reports on aspects of this interdisciplinary collaboration.

JMSCE Special Issue Articles

A Tale of Four Departments: Interdisciplinary Faculty Learning Communities Informing Mathematics Education discusses how a faculty learning community (FLC) was created and cultivated at Lee University and how it was used to implement interventions in different mathematics courses. Individual perspectives of participating faculty from mathematics, behavioral and social sciences, natural sciences, and education are provided.

Improving Student Knowledge Transfer Between Mathematics and Engineering Courses Through Structured Cross-Disciplinary Collaboration: A SUMMIT-P Initiative describes the decision to initially focus on collaboration between engineering and mathematics faculty at Virginia Commonwealth University (VCU). This collaborative effort concentrated on the Differential Equations course offered by the mathematics department and the use of differential equations in engineering courses. This decision was based on faculty surveys and the high level of interest and sense of urgency during fishbowl conversations. The paper presents several examples of disparate terminology, including problems with notation and convention in mathematics and engineering, and describes strategies for bridging this gap.

Using an Interdisciplinary Case Study to Incorporate Quantitative Reasoning in Social Work, Nursing, and Mathematics outlines ways in which faculty from social work, nursing, and mathematics developed a case study about Hurricane Katrina—as a response to the potential for a malaria breakout, and including the necessary calculations of financial costs for emergency shelter, water, food, and medicine. The case study allows faculty to use the lens of social justice to teach mathematical concepts and provides an avenue for nursing and social work students to engage in mathematics through a situation germane to their profession. The paper includes sidebar contributions from other SUMMIT-P institutions describing similar cross-disciplinary collaborations.

Just in Time Mathematics Review for Accounting Students describes how initial conversations clarified the biggest concern in the minds of many business faculty: weaknesses in mathematical backgrounds of many students entering business classes. In this case, the faculty learning community took the form of a mathematics-business committee that met monthly, undertaking such initiatives as: developing a college algebra course with a business focus; using GeoGebra as an in-class visualization tool; and providing mathematics reviews for accounting students.

Leveraging Interdisciplinary Expertise in Developing an Alternative Mathematics Pathway highlights ways in which faculty from mathematics, statistics, humanities, and communication collaboratively developed two mathematics courses designed to meet the needs of students not majoring in Science, Technology, Engineering, and Mathematics (STEM) disciplines. Because these courses contain humanities- and communication-focused elements, as well as sufficient mathematics content, they can help students attain multiple and diverse general education competencies. The paper describes the content of the courses, communication issues among faculty with differing ideas, and navigation of the administrative process for non-conventional courses and team teaching across disciplines.

Statistics for Nursing and Allied Health at Saint Louis University in the Spirit of SUMMIT-P describes the interdisciplinary collaboration that resulted in the development of a statistics course designed to meet the needs of students majoring in nursing and allied health disciplines. The environment for the collaboration was unique because the course development was not formally part of SUMMIT-P. Instead, it was a spin-off from the SUMMIT-P work supported by the broader university, highlighting the importance of the institution's long-term support for interdisciplinary collaboration.

An Examination of Factors that Support Sustainable Cultural and Curricular Change in STEM Teaching and Learning outlines how the evaluation team collected data from the interdisciplinary faculty learning communities at SUMMIT-P institutions through participants' responses to periodic prompts, participation in site visits, and individual interviews and focus groups. An emergent model has been developed to assist in understanding the factors that contribute to the sustainability of innovations in educational settings. Important outcomes from the SUMMIT-P work are discussed, including the impact of institutional leadership, the creation of sustainable change, and the need for comprehensive buy-in and support.

Acknowledgment

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A Tale of Four Departments: Interdisciplinary Faculty Learning Communities Informing Mathematics Education

Bryan D. Poole
Lee University
bpoole@leeuniversity.edu

Caroline Maher-Boulis
Lee University
cmaherboulis@leeuniversity.edu

John Hearn
Lee University
jhearn@leeuniversity.edu

Jason Robinson
Lee University
jrobinson@leeuniversity.edu

Patricia McClung
Lee University
pmcclung@leeuniversity.edu

Amanda Jones
Lee University
amandajones@leeuniversity.edu

https://doi.org/10.25891/9bqk-av84

Abstract
As a result of the Curriculum Foundations Project and the SUMMIT-P consortium, faculty from four different departments at Lee University created a Faculty Learning Community (FLC) with the goal of improving students' attitudes toward undergraduate mathematics courses, including students' perception of the utility of mathematics in their lives and the feelings of anxiety that they experience in these courses. The interdisciplinary collaborations resulted in introducing novel activities and manipulatives in various mathematics courses (Introduction to Statistics, Concepts of Mathematics I and II, and Algebra for Calculus). This paper first describes the efforts of creating the inter-departmental FLC. Second, it discusses the interventions that were introduced in the mathematics courses. Finally, it reflects on the lessons learned while participating in the learning community. The goal is to guide and challenge readers to consider how similar collaborative opportunities can be initiated at their own institutions.

Keywords
Faculty Learning Community, interdisciplinary, mathematics, education

The Curriculum Foundations (CF) Project was part of an extensive review by the Mathematical Association of America of undergraduate programs in mathematics from 1999 to 2007 (see Ganter & Barker, 2004; Ganter & Haver, 2011). Specifically, the CF Project hosted workshops for 22 disciplines to assist mathematics faculty in gathering information about the mathematics concepts and skills that are important for students understand when pursuing majors in the partner disciplines. The findings from these workshops were summarized in Ganter and Barker (2004) to help guide changes to undergraduate mathematics instruction. One of the important conclusions was that, "Promoting and supporting informed interdepartmental discussions about the undergraduate curriculum might ultimately be the most important outcome of the Curriculum Foundations Project" (Ganter & Barker, 2004, p. 6).

Recommendations from the CF Project led to the creation of a National Consortium for Synergistic Undergraduate Mathematics via Multi-institutional Teaching Partnerships (SUMMIT-P), a large-scale project uniting numerous colleges and universities with the mission of creating Faculty Learning Communities (FLCs) consisting of mathematicians and faculty from other disciplines. These FLCs were tasked with discussing ways to implement the CF recommendations in targeted mathematics courses and, by extension, improve student learning.

In this paper, faculty at Lee University describe the process of creating and cultivating a FLC, and using the FLC to implement interventions in different mathematics courses. Challenges to maintaining a FLC, proposed solutions to these challenges, and the impact of the FLC on both faculty and students will also be discussed.

Defining and Creating a Faculty Learning Community

FLCs are "collaborative collegial groups of faculty and other teaching staff who are interested in and committed to the improvement of their teaching to accommodate a diverse student population through group discourse, reflection and goal setting" (Ward & Selvester, 2011, p. 2). FLCs may function to address the needs of a specific group of faculty or staff, or focus on improving teaching and learning through interdisciplinary collaboration (Cox, 2004; Nugent et al., 2008). These collaborations may improve teachers' confidence and understanding of how students learn (O'Meara, 2005). In addition, FLCs have positive benefits for student learning, including better class discussions, written work, and class atmosphere (Beach & Cox, 2009).

Given the mission of SUMMIT-P and results of the existing research on FLCs, faculty at Lee University sought to create a learning community to implement the CF recommendations in mathematics courses. Lee is a small, liberal arts institution in the southeastern United States comprising approximately 5,000 students. Most students are required to complete at least one mathematics course, such as Introduction to Statistics, as part of an undergraduate major, in a discipline such as biology, chemistry, political science, psychology, criminal justice, nursing, education, or mathematics.

Because students taking mathematics courses represent a breadth of disciplines, our FLC consists of faculty from four departments: Mathematical Sciences; Behavioral and Social Sciences; Natural Sciences; and Early Childhood, Elementary, and Special Education. A summary from each participating faculty member about how the FLC was formed and utilized to improve student learning is outlined below.

Caroline Maher-Boulis, Department of Mathematical Sciences

As the PI of the project, I initiated the collaboration between the co-PIs representing each of the departments by first consulting the CF Project's publication, *Voices of the Partner Disciplines*, (Ganter & Barker, 2004), for discipline-specific recommendations. We reviewed the recommendations for chemistry (Ganter & Barker, 2004) and for Teacher Preparation: K-12 Mathematics (Ganter & Barker, 2004). The Social Science recommendations came from the document developed through phase II of the CF Project (Ganter & Haver, 2011). We then selected five mathematics courses on which to focus our work: Introduction to Statistics (with Behavioral and Social Sciences as the partner discipline); Algebra for Calculus (with Natural Sciences as the partner discipline); and College Algebra, Concepts of Mathematics I, and Concepts of Mathematics II (with Education as the partner discipline). This initial step acquainted us with the concept of a FLC and provided preliminary information about the partner disciplines' mathematical needs.

Bryan Poole, Department of Behavioral and Social Sciences

My department is composed of students majoring in psychology, sociology, and anthropology. All students are required to pass Introduction to Statistics before they can register for the mathematics-focused courses in the major. Psychology majors take Introduction to Research Methods and Statistics. Sociology and anthropology majors take Research Methods and Statistics I. Together, these courses emphasize many of the concepts that are taught in Introduction to Statistics, such as descriptive statistics, properties of a normal distribution, and graphical representations of data, and provide students with opportunities to apply these concepts. Not surprisingly, many of our students have a difficult time transitioning from Introduction to Statistics into their major methods and statistics courses, primarily because they tend to forget some of the course content, are unable to connect content from one course to another, or experience anxiety related to studying the content.

One of my first tasks as a partner discipline representative was to consult the CF recommendations, which include a list of necessary, desirable, and optimal skills for the social sciences (Ganter & Haver, 2011). Reviewing these skills provided a springboard for conversations with my psychology and sociology colleagues, who shared through the FLC their recommendations about which of these skills should be emphasized. Our discussions produced a wish list containing eight skills that we wanted to be highlighted in Introduction to Statistics.

My next task was to align the contents of my department's wish list and the CF recommendations with the topics listed in the Introduction to Statistics syllabus. For example, correlation and regression in the syllabus correspond to the CF recommendations and wish list items of conceptual understanding; understanding graphical representation and interpretation; and grouping problems in a social science context. Mapping wish list items with course topics paved the way for additional discussions between members of the FLC and mathematics faculty about where various skills should fit into the Introduction to Statistics curriculum.

John Hearn, Department of Natural Sciences

Many science students dread the mathematical components of chemistry and biology. Chemistry, in particular, has many mathematical concepts and skills integrated throughout the curriculum. Students, therefore, must transfer their mathematical knowledge into the science classroom. Some problems require algebraic manipulation, other problems require graphical interpretation, and still other problems require simplification to understand the functional dependencies between variables. These and other mathematical knowledge and skills are prerequisites for many college-level science courses.

I began my involvement with the FLC by reviewing the CF recommendations for chemistry and biology (Ganter & Barker, 2004). Then I gathered input from both biology and chemistry faculty about which algebraic concepts and skills were most important in the classes they teach. We organized this input into a wish list of high priority concepts and skills that the science faculty at Lee believe are important prerequisites for their students. We then met with mathematics faculty to discuss the learning objectives for Algebra for Calculus to determine whether these concepts and skills are addressed. Overall, there was good overlap between the needs of the chemistry and biology faculty and the learning objectives in the algebra class. Every concept or skill aligned with a specific learning objective listed on the syllabus. One learning objective, while listed on the syllabus, was not historically covered in the algebra class—logarithms. Students taking General Chemistry II need a well-developed understanding of these functions and need to be proficient at algebraically rearranging equations with logarithms and exponents. The FLC discussed ways in which the algebra class could be revised to include a full treatment of logarithms.

Following this initial meeting, the collaboration was maintained in two ways. First, I worked with biology, chemistry, and mathematics faculty to develop activities that the algebra faculty could use in their classes. These activities help students explore the application of algebraic concepts and skills to chemical and biological problems. The activities begin by providing a short introduction of the chemical or biological topics followed by the algebraic problem needed to solve problems in these subject areas. Students then solve the algebra problem in by applying mathematics concepts ranging from algebraic manipulation to graphical interpretation.

Second, the chemistry faculty are engaged in ongoing discussions about how they can help bridge the gap between preparatory mathematics classes and chemistry classes. I made supplemental videos to demonstrate how to algebraically manipulate chemical equations, how to use calculators, and how to solve more advanced functions numerically. The chemistry faculty has also revised the general chemistry courses to help students succeed who often struggle with some of the mathematical concepts and skills needed to solve chemistry problems. The overall goal is to make a path for students to overcome challenging algebraic concepts and skills by providing the necessary scaffolding, tutoring, and practice.

Jason Robinson, Department of Early Childhood, Elementary, and Special Education

The Helen DeVos College of Education is composed of two departments: Early Childhood, Elementary, and Special Education (ECESE) and Health, Exercise Science, and Secondary Education (HESSE). ECESE students are required to take several mathematics courses including Concepts of Mathematics I, Concepts of Mathematics II, and College Algebra. HESSE students, depending on the major, could be required to take up to 16 hours of mathematics courses in addition to the general core curriculum. Many of our students, especially in the ECESE department, express high levels of mathematics anxiety and hesitation about taking mathematics courses and completing math-focused assessments. This anxiety has caused our students to postpone required courses until the last minute and has even resulted in delayed graduation for some due to not registering for classes or avoiding the tests required for Tennessee teacher certification.

As a partner discipline representative, my first task was to examine the CF *Voices of the Partner Disciplines* publication (Ganter & Barker, 2004) which includes a list of five principles to guide the preparation of teachers, specifically in mathematics. During an ECESE departmental meeting, faculty discussed these principles in detail and selected two to be the focus of our mathematics courses for preservice teachers (Concepts of Mathematics I & II and an elementary teaching methods course). Our wish list was comprised of these two principles.

I spoke extensively with mathematics faculty who were teaching courses for College of Education students. Those discussions and collaborations provided rich opportunities to learn from one another and gain insight into various pedagogical practices that were currently being employed in both education and mathematics classes. In addition to the enlightening discussions, faculty also visited each other's classrooms to observe and document teaching practices. After quickly discovering that students' mathematics anxiety was high, we determined to do everything possible to decrease their anxiety and help them feel more comfortable in and prepared for their mathematics courses. That is, it was clear that the two items on our wish list extremely relevant and applicable. The principles we focused on are:

1. Tools for teaching and learning, such as calculators, computers, and physical objects, including manipulatives commonly found in schools, should be available for problem solving in mathematics courses taken by prospective teachers.
2. Mathematics courses for future teachers should provide opportunities for students to learn mathematics using a variety of instructional methods, including many we would like them to use in their teaching.

Expanding the Faculty Learning Community

The FLC hosted additional meetings to facilitate the collaboration between mathematics and partner discipline faculty. For example, a fishbowl activity took place in which faculty from the collaborating departments discussed the mathematical needs of their disciplines, while the mathematics faculty listened and took notes. Meetings with faculty from individual departments were scheduled to further support the collaboration, discuss ideas for interventions, and learn more about the topics and skills included on the wish lists of the partner disciplines.

Caroline Maher-Boulis, Department of Mathematical Sciences

As the instructor for Algebra for Calculus, I listened to the discussions of faculty from the chemistry, biology, and health science disciplines during the fishbowl activity. The activity allowed me to learn about and better understand the needs of the disciplines that require students to take Algebra for Calculus. The discussions revealed that partner discipline faculty assumed some algebra topics were being addressed in the course while in fact they were not. This was a significant revelation to both parties that illustrated the need for more class time to cover these topics many of which were addressed toward the end of the course. Consequently, faculty proposed the course to be redesigned as a four-credit-hour course instead of a three-credit-hour course. Moreover, faculty from the health science division provided ideas for application problems to be created for use in the course.

Individual meetings with some other departments were not as effective. Although they shed light on why the departments require students to take the course, the meetings did not result in the development of specific applications that could be effectively used in the course.

Amanda Jones, Department of Mathematical Sciences

During the initial meetings, I was teaching only one of the courses highlighted in this project, Introduction to Statistics. By attending the fishbowl activity, I was able to learn from my colleagues in the social sciences. I was also presented with the wish list and the map of how different the items aligned with topics in the course syllabus. I listened as my colleagues talked through challenges with trying to teach concepts in their disciplines that built on material that was covered in my course. As we continued to have more fishbowl meetings, I learned more about which topics were important to other departments across campus, such as the School of Business, the HESSE department, and others. One theme that was consistent across each discipline was the desire to have incoming students be more proficient in working with Excel. This inspired me to add activities to my course that required students to use this program. I also made supplemental videos that introduced basic concepts to students who were unfamiliar with Excel. Another outcome from these meetings was problem sets developed by Bryan Poole that incorporate social science contexts for use in the statistics course.

While I was not involved in the initial meetings with the College of Education faculty, I began teaching Concepts of Mathematics I a year later. When this course was assigned to me, I attended a similar fishbowl where I heard from College of Education faculty about their needs for this course. Specifically, faculty indicated that students enrolled in the course would benefit from the use of mathematical manipulatives to help the students develop a deeper understanding of the content. Future teachers also benefit from using manipulatives as they need learn how to use them in the classroom.

Patricia McClung, Department of Early Childhood, Elementary, and Special Education

As Chair of the ECESE department, it has been a pleasure to watch the ongoing collaboration that has taken place between the Helen DeVos College of Education and various partner disciplines. On the university campus, collaborations like this are not always the norm.

The initial fishbowl activity was extremely important for several reasons. First, it provided an opportunity for the SUMMIT-P team to inform key leaders about the project and to cast a vision for this project on our campus. Second, the activity provided rich conversation and collaboration among faculty members and university administration. Third, it provided partner disciplines with an opportunity to not only share strengths, but also areas of need in our content areas. And lastly, the fishbowl activity gave participants an opportunity to recognize overlapping content present in our programs and discuss ways to use those similarities for the betterment of our students.

Once the fishbowl activity was completed, Jason Robinson began to communicate directly with education and mathematics faculty members about the wish list and how the needs of partner disciplines could be addressed. Additional fishbowl activities took place, classroom observations were scheduled, and the FLC was quickly providing the necessary support and guidance for changes in our classes.

The impact of this team did not only involve faculty from education, mathematics, and social sciences. The SUMMIT-P team also felt it was important to introduce their work to faculty members across campus. They provided several sessions in the Center for Teaching Excellence and also collaborated further with faculty members in other ways.

Introducing Changes to Mathematics Courses

The next step for the FLC was utilizing the information gathered from meetings with other faculty, the partner discipline wish lists and syllabus maps, to implement the CF recommendations in the targeted mathematics courses. Specifically, various interventions that were designed to improve students' understanding of and attitudes toward mathematics were selected and developed. What follows is a discussion of how these interventions were chosen and used in the mathematics classroom.

John Hearn, Department of Natural Sciences

The chemistry and biology faculty recommended one course change and provided a series of activities to be resources for the classroom or used as supplements to homework assignments. First, we recommended that the Algebra for Calculus course be revised to include a thorough focus on logarithms. To accommodate this change, we examined the course topics and recognized that equations with one unknown can be treated as a special case of equations with two variables. We recommended that less time be devoted to equations with one unknown to allow for time later in the semester for introducing logarithms.

Second, we provided a series of activities as resources for algebra faculty to use. These activities, which focus on a variety of algebraic skills and competencies, show the application of algebra in health science (medicine dosage), biology (population dynamics), and chemistry (Haber process and equilibrium concentrations). The activities include graphically analyzing data, graphically solving complex polynomial equations, algebraically manipulating equations, and rearranging and interpreting equations with variables other than x and y. All of these skills align with the CF recommendations (Ganter & Barker, 2004). Each activity includes a discipline-specific introduction. In some activities, a worked example is provided so that students can see the application of the algebraic concepts and skills to the types of problems being featured. This type of direct instruction is argued to be the most efficient method of learning for most students (Clark et al., 2012; Rosenshine, 2012).

Caroline Maher-Boulis, Department of Mathematical Sciences

Of the interventions mentioned above for the Algebra for Calculus course, the activities with applications to health science and biology were used in the class. These applications cover the concepts of linear equations in two variables, functions, graphs and their interpretations. The students practice manipulating equations algebraically, rearranging and interpreting them and analyzing data.

I try to introduce these interventions at the appropriate time according to the level of difficulty as well as the concepts and skills covered in the course. I typically start with the interventions that feature functions, as they give the students an introduction to the concept and solidify the terminology used (e.g., independent and dependent variables, domain and range) throughout the course while providing a simple application to the mathematical concept. As students learn more about different types of functions, I assign the intervention on population dynamics which involves the simplest of functions, linear functions. In this intervention students are given a table of values showing population changes in light and dark moths over nine years. Students are asked to plot the data points and find lines of best fit. They are then asked to calculate slopes, find intercepts, and write equations representing each linear function, and to interpret these quantities as well as the information presented in graphs.

Throughout the course, students are exposed to the concept of functions in various ways (i.e., verbally, graphically, algebraically, and numerically) and become more comfortable working with functions. It is at this stage that I assign the health science application on medicine dosage, which helps students realize that graphs of functions need not be continuous and may not be in any of the familiar forms covered in class (e.g., polynomials, exponential functions, logarithmic functions). The last intervention I use is a population growth problem, which introduces students to the future calculus concept, rates of change.

I have not been able to use the chemistry interventions to date, as they were too technical for the students. It is our intention to continue working on these interventions to make them more accessible to the level of students in the Algebra for Calculus class.

Bryan Poole, Department of Behavioral and Social Sciences

To address the items on my department's wish list, I recommended three types of interventions to be used in Introduction to Statistics. First, to help students see how various statistical concepts (e.g., the normal distribution, central tendency, data visualization) can be applied in other disciplines, I provided mathematics faculty with a list of problems relevant to social science majors. For example, in one problem students are presented with a table of data and are asked to decide which of four bar graphs best represents the raw data. Instructors are encouraged to assign these items as in-class activities or as part of a homework assignment.

After the mathematics faculty provided feedback about these problems, I converted many of the questions into prompts for group discussions or debates to increase the likelihood of faculty utilizing them and students engaging with them. For example, one prompt requires two teams of students to debate whether it is appropriate to compare the mean age for marriage in Canada and the median age for marriage in the United States. I also retained the format of some individual questions focused on social science content in case instructors wanted to use them in other ways.

Second, I recommended the use of manipulatives called Poker Chip People (Sledjeski, 2016), a resource designed to help students simulate sampling from a diverse population and to facilitate statistical analyses with realistic data. Instructors present students with a bag containing 100 poker chips that represent 100 people, each of which is covered by a colored label containing information about that person (e.g., gender, happiness level, and income). After students draw chips from the bag, they are instructed to practice various statistical analyses (e.g., descriptive statistics, probabilities, linear regression) that are outlined in the accompanying resource manual.

After purchasing enough poker chips, labels, and bags to accommodate multiple instructors, I met with the mathematics faculty to introduce the manipulatives. Each instructor received their own bag of chips and a resource manual. They submitted questions and provided feedback about the manipulatives before using them in Introduction to Statistics. In addition, I also helped create a spreadsheet to simulate the use of these manipulatives in the event that faculty are unable to use them or do not wish to use the actual poker chips in their classroom (e.g., for hygiene purposes). After years of use, mathematics faculty have suggested that these manipulatives have improved their students' enjoyment and understanding of statistics.

Finally, I helped organize the Student Exchange Program (SEP), a student learning community designed to facilitate opportunities for interdisciplinary collaboration between students majoring in mathematics and social sciences (Poole et al., 2020). Students in the SEP work together to complete various activities designed to improve their conceptual understanding and perceived utility of statistics. Some of their activities, such as generating problems, leading recitation sections, developing novel manipulatives, and tutoring, have also aided students enrolled in Introduction to Statistics.

Amanda Jones, Department of Mathematical Sciences

Broadly, I found the recommendations and interventions helpful in both the Introduction to Statistics course and the Concepts of Mathematics I course. For example, I used the list of problems provided by Bryan Poole in many ways. I inserted them into problem sets, incorporated them into class discussions, and even used the questions on exams. I consistently use the Poker Chip People activity to demonstrate different sampling methods. I found both of these interventions useful not only for the social science majors in my courses, but for most of my other students, as well.

In addition to being an instructor of Introduction to Statistics, I am also the director of the Mathematics Tutoring Lab, which is primarily visited by students enrolled in the statistics course. I have found that one of the best outcomes of the statistics part of this project is the development of the Student Exchange Program, which has provided staff for the tutoring lab, ensured statistics students could get additional help outside of class, and created valuable conversations between mathematics and social science majors as they have tutored statistics students.

Jason Robinson, Department of Early Childhood, Elementary, and Special Education

The department's wish list provided the framework needed to make changes to our mathematics courses for preservice teachers. With the CF document as our guide, interventions were made in Concepts of Mathematics I and II and in an elementary methods of teaching course.

The first intervention introduced was the addition of manipulatives in mathematics instruction, such as fraction towers and Base 10 blocks. After visiting Concepts of Mathematics I and II, I immediately recognized a need for incorporating manipulative use in instruction. Students were frustrated and anxious because of their lack of understanding about course content. According to Stein and Bovalino (2001), manipulatives are very important tools that can help students think and reason in meaningful ways. Sutton and Krueger (2002) found that with the use of manipulatives, students' mathematical interest was increased. In the elementary and middle school classrooms, where many of our students find careers, manipulatives are not only used, but are expected to be incorporated in mathematics lessons. For these reasons, manipulative use was recommended as an intervention in our classes for preservice teachers.

The methods by which a teacher introduces manipulatives plays a significant role in how well the concepts transfer to students. For this reason, it is very important that teachers understand how to appropriately use manipulatives during the instructional time (Robinson et al., 2020). Professional development training on the use of manipulatives in the classroom was conducted by a mathematics specialist from the local school district for education and mathematics faculty. These training sessions offered a unique opportunity for faculty members to learn about new manipulatives being used in classrooms, in addition to current pedagogical practices.

Another intervention that was recommended was a restructuring of the mathematics manipulatives exam taken by students who complete a course in elementary teaching methods. After a close review of the exam, we found that manipulative use in the course was minimal, and the tools used were often outdated and no longer relevant for the classroom. For that reason, I had extensive conversations with public school teachers about the current use of manipulatives in K-8 classrooms and the various pedagogical practices that were employed when teaching mathematics to elementary and middle school students. I shared my findings with the instructor who focuses on mathematics instruction in the elementary teaching methods course. This eventually led to us purchasing additional mathematics manipulatives and beginning the work of restructuring the outdated mathematics manipulatives exam. This work is ongoing and will continue so that we can ensure that our practices and methods are relevant for students preparing to teach in public-school classrooms.

Amanda Jones, Department of Mathematical Sciences

For Concepts of Mathematics I and II, I have been provided with class sets of valuable manipulatives, such as Base 10 blocks, snap cubes, Cuisenaire rods, and fraction towers to use. I regularly use these manipulatives to demonstrate concepts and have students practice teaching each other with these materials. Robinson et al. (2020) provides more details on how these manipulatives are used effectively in the classroom. This project has also funded two different workshops with a mathematics specialist to reinforce and enhance how to use these manipulatives in instruction.

Patricia McClung, Department of Early Childhood, Elementary, and Special Education

At the end of the first semester of the senior year (Clinical Semester I), elementary education majors complete a mathematics manipulative exam to assess their ability to conceptualize various mathematics concepts and to teach them to children in PK-5 classrooms. In addition to understanding the concepts, each candidate also demonstrates their ability to teach mathematics concepts in a variety of PK-5 settings.

Manipulative use in Concepts of Mathematics I and II for elementary majors has also been an intervention that has been vital to the success of our students. A required mathematics task assessment is another area where we have seen growth, not only in student confidence level but also in overall achievement. After ideas were shared and strategies were gathered from the collaboration between the Department of Mathematical Sciences and the College of Education, an improvement was noted in the teacher candidates' abilities to both solve mathematical tasks and teach them. The scores for the mathematics task assessment increased and there was a noticeable difference in the affective stance of the candidates. They portrayed more confidence and conviction concerning their preparation for and performance on this particular assessment.

Professors who supervise student teachers have seen a direct correlation between the increased use of manipulatives in the relevant courses taught in the College of Education and the Department of Mathematical Sciences and in the performance-based assessment that is required of all teacher candidates. Additionally, candidates reported greater ease in the student teaching setting. It has been noted that PK-5 students were more engaged, and they made meaningful connections between real world situations and mathematics. Students in the classroom were also physically involved in the learning process and were able to visualize different scenarios and outcomes.

Another unexpected outcome of the interventions revolved around the ability to translate the effects of using manipulatives into the virtual world during the time of the COVID-19 pandemic. Many of the student teachers were required to teach virtually and were at ease teaching with virtual manipulatives in the online mathematics classroom. This was an added benefit for teacher candidates and for student engagement overall.

Lessons Learned

Several challenges were encountered while sustaining the FLC. The first challenge faced, and perhaps the most prevailing one, is receiving faculty buy-in for initiatives like the one undertaken at Lee University. The interdisciplinary collaborations worked well in the Algebra for Calculus and Concepts of Mathematics I and II but not so well in College Algebra and Introduction to Statistics. Faculty members of the former classes saw the real benefit of these collaborations and were open to learning new techniques and listening to the needs of the partner disciplines. Conversely, very few faculty members in the latter courses saw the benefits or were open to sharing and communicating their knowledge and sharing their experiences.

Another challenge for faculty involvement in revising a first-year mathematics class, such as Algebra for Calculus, is that many science students begin their college-level mathematics at a level higher than algebra. Those students will not receive any benefit of curricular or pedagogical revisions to the Algebra for Calculus class, because they will never take the class. This diminished return on investment tends to shift the faculty focus to other endeavors.

A more general challenge facing our FLC is measuring its effect on student learning. So far, efforts to quantify the effects on student performance in general chemistry has yielded no statistically significant difference between students who have taken the Algebra for Calculus class, for instance, and students who tested out of algebra. A broader and more lasting impact to faculty would naturally follow when student learning measurably improves.

Despite these challenges, several successes were also experienced throughout the FLC. For example, participating in the FLC has afforded faculty the opportunity to exit their discipline-specific silos, learn more about the needs of other departments, and enjoy the camaraderie afforded by frequent communication (Bishop et al., 2020). The common goal of improving student learning has been a catalyst for unification and successful discussions during the last five years.

In addition, the FLC has established a collaborative network that affords ongoing, sustainable partnerships between mathematics and partner discipline faculty that may last beyond the lifespan of SUMMIT-P. Even now, as the FLC extends into its sixth year, faculty are actively seeking ways to improve students' ability to transfer knowledge from mathematics courses into partner discipline courses. For example, social science and mathematics faculty are currently working together to test new interventions that help students solve statistics problems by comparing and contrasting multiple problem-solving strategies (see Rittle-Johnson et al., 2020). Chemistry faculty are seeking to develop a required “mathematics for chemistry” class for all first-year students to cover a variety of topics (graphical analysis, how to use a calculator, spreadsheet analysis, etc.), as well as the computational skills students need to be successful for college level chemistry. Furthermore, chemistry faculty are discussing a remedial co-requisite course for students who test out of algebra but are not proficient on prerequisite algebraic concepts. This remediation, which has been effective at Texas Tech University (Hesser & Gregory, 2016), would be required for all students who do not meet the prerequisite knowledge standards. Taken together, these efforts at revising the curricula will benefit from continued collaboration with mathematics faculty.

Conclusion

FLCs provide a host of benefits and challenges for participating faculty and staff. For example, they can serve as the catalyst for interdisciplinary collaboration, break down discipline-specific silos in academia, and increase camaraderie among participants. More importantly, FLCs can provide novel opportunities to improve student learning. By sharing the details about the FLC formation and activities, the goal has been to guide and challenge readers to consider whether similar collaborative opportunities can be initiated at their own institutions.

Sidebar

As mentioned at the beginning of this paper, SUMMIT-P is a multi-institutional project in which all participating institutions created their own FLCs. What follows is a description of how similar FLCs, from four departments, were formed at Ferris State University. This sidebar also discusses the challenges faced at that institution, some of which are similar to challenges faced at Lee University.

FLCs at Ferris State University

As co-PIs of the Summit-P project at Ferris State University, we initiated the idea of facilitating a FLC by bringing together faculty from a variety of disciplines. One of our main goals of the FLC was to create a plan to teach mathematics and quantitative reasoning concepts across disciplines in an attempt to reduce student mathematics anxiety. Members of the SUMMIT-P team at Ferris reached out to faculty in social work, nursing, business, and mathematics, which ultimately led to the creation of four interdisciplinary teams that all met together every three weeks. These teams consisted of one faculty from mathematics and one from each of the other three disciplines. While the pedagogical strategy (a case scenario involving Hurricane Katrina) developed and implemented into identified courses in each of the four disciplines was generally successful, it was not without its challenges. Among the challenges we faced were (1) having faculty join the FLC primarily for the stipend associated with it; (2) developing an assessment plan to measure changes in student mathematics anxiety; (3) unexpectedly having to spend time learning the “languages” of the four disciplines; and (4) working with non-mathematics faculty who were not skilled in teaching mathematics concepts in their discipline.

Because our FLC was supported by our Faculty Center for Teaching and Learning, all participating faculty were provided with a $1200 stipend for completing the year-long commitment. Getting any group of faculty members together every three weeks over the course of a year is difficult, and the FLC proved to be no exception. The attendance and amount of work put forth varied among FLC participants. Though all participants actively participated in creating a set of community norms at the beginning of the FLC, not everyone was equally committed to them. This left their team members to do more work than they initially anticipated, and made it difficult to establish cohesion among members of the whole group. In the future, it would be well worth the effort to interview the people who volunteer to participate to better understand their motivation and expectations for participating.

A second challenge was the development of an assessment plan to examine outcomes associated with the implementation of the case scenario. While an assessment plan was discussed by the SUMMIT-P team at Ferris, there was little time between the decision to host a FLC and the start of the FLC. In most circumstances, an assessment plan is developed at the beginning of a project such as this and helps guide the development and implementation of the intervention. In our case, several cohorts of students have now been exposed to the intervention and an assessment plan is still not in place. While there are anecdotal accounts from faculty as well as assignment and course grades, we do not have specifically linked assessment measures of mathematics anxiety in place. This impairs our ability to conclude that the interventions we designed and implemented work to reduce mathematics anxiety.

A third challenge we experienced was underestimating the time and effort it would take for team members to learn the languages of the other team members. Even basic terms like "variable" were used differently in each of the disciplines. Without a mutual understanding of how the mathematics concepts were used in the various disciplines, it was sometimes difficult for team members to communicate as to how best to implement the case scenario in mathematics courses and in the respective disciplines.

The fourth challenge we faced was that faculty from social work, nursing, and business had not themselves taken a mathematics course in many years, and felt unprepared to teach mathematics concepts in their non-mathematics courses. This necessitated that the mathematics faculty "re-educate" the faculty in other disciplines on basic mathematics concepts like proportions, linear functions, and exponentials, and assist them in developing applications in their specific disciplines. Although this was challenging for all faculty, one of the benefits of the challenge was that non-mathematics faculty now better understand those basic concepts, and mathematics faculty gained experience in teaching the concepts to the FLC participants, who like their own students, had almost completely forgotten them.

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Improving Student Knowledge Transfer between Mathematics and Engineering Courses Through Structured Cross-Disciplinary Collaboration: A SUMMIT-P Initiative

Laura Ellwein Fix
Virginia Commonwealth University
lellwein@vcu.edu

Afroditi Filippas
Virginia Commonwealth University
avfilippas@vcu.edu

Maila Brucal-Hallare
Norfolk State University
mcbrucal-hallare@nsu.edu

Rebecca Segal
Virginia Commonwealth University
rasegal@vcu.edu

https://doi.org/10.25891/c4pf-vx57

Abstract

Student learning across STEM disciplines has been shown to increase with greater integration of applications in mathematics courses. One challenge of this effort is that identical constructs are often presented differently in the partner disciplines than in the mathematics courses. This leads to student confusion and an inability to transfer critical knowledge in their disciplinary courses, even for students who have mastered the mathematical paradigms. An interdisciplinary team at VCU consisting of mathematics and engineering faculty has worked to improve the knowledge transfer required for the integration of applications in the Differential Equations curriculum. This work is part of the multi-institutional SUMMIT-P initiative which aims to transform first- and second-year mathematics through collaboration with partner disciplines. The collaborative efforts have uncovered a variety of differently presented but identical constructs in categories ranging from notation up through higher-level interpretation. We provide some specific examples and analyses of these constructs and the implications for knowledge transfer and pedagogical concerns. Conversations around mathematics and disciplinary imperatives served to create a holistic view of the role mathematics and partner discipline professors have in improving learning outcomes.

Keywords

interdisciplinary, translation, concept mapping, applications, curriculum development

Current research indicates that student learning across STEM disciplines increases as the integration of applications in mathematics courses via interdisciplinary faculty partnerships increases (Filippas et al., 2020). Fostering such a beneficial partnership can be challenging especially in a large, research-intensive urban institution such as Virginia Commonwealth University (VCU). At VCU, mathematics and engineering faculty alike have repeatedly witnessed that students enrolled in traditional STEM curricula often have difficulty transferring knowledge between mathematics classes and their major discipline, ranging from elementary terminology to overarching concepts. Several faculty across these disciplines have taken on the initiative to improve student knowledge transfer as part of the larger project, A National Consortium for Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnership (SUMMIT-P).

SUMMIT-P is an extension of work begun in the Curriculum Renewal Across the First Two Years (CRAFTY) project (Ganter & Haver, 2020). The central goal of SUMMIT-P is to develop innovative educational paradigms via collaborative, interdisciplinary partnerships, and thereby improve mathematics instruction for students of all disciplines. Each institution within the consortium developed its own strategies and collaborations based on its perceived needs or preferences. VCU has been an active institution in SUMMIT-P since its launch in the Fall semester of 2016. The VCU team, led by a mathematics PI and an engineering co-PI and including additional faculty from both disciplines, has worked to use interdisciplinary faculty partnerships to effect change in the undergraduate mathematics curriculum with a particular focus on connections to engineering.

Grant activities for beginning structured engagement in productive conversations with faculty across disciplines included site visits (Hofrenning et al., 2020), classroom visits, and “fishbowl” style conversations (Piercey et al., 2020) in which one group of participants observes the discussions of the other group. Given the energy required for an effective fishbowl conversation, our experience indicated that we would not be able to engage mathematics or partner discipline faculty in more than one. Therefore prior to any discussions, the VCU team surveyed all STEM faculty to assess the needs of faculty and students, gather information about their needs for specific course content in a variety of mathematics courses, and develop a sense of the degree to which faculty would be engaged in this process. One of the first strategic choices the team made after the results of the survey were analyzed was to use Differential Equations as our pilot course. This decision was made in part to allow us to develop our learning modules for a smaller cohort of primarily engineering students with similar backgrounds and interests, and later apply them to the more general-interest courses. A second consideration was the high level of interest and sense of urgency imparted by engineering faculty as evidenced by the degree to which they engaged with the survey.

Throughout the conversations about differential equations and engineering, the team has come to recognize that identical mathematical constructs and engineering systems are often presented differently in the partner disciplines when compared to this and other mathematics courses. This leads to confusion and the inability to transfer critical knowledge to disciplinary courses regardless of the level of mastery of mathematical paradigms. What has emerged is a long-term effort to create and maintain a durable infrastructure for discussing terminology, concepts, and applications in the mathematics courses that align with how the students will need to access the content in their subsequent engineering or science courses. This requires regular contact between mathematics and engineering faculty to continuously update and improve our interdisciplinary network of discipline-specific terms, notation, and concepts. Our conversations and collaborations on teaching have evolved from specific content topic concerns, to shared application examples, to the current process we are engaged in of developing a shared mapping. Below, we provide some specific examples of differently presented but identical constructs in categories ranging from notation up through higher-level interpretation and the implications for knowledge transfer and pedagogical concerns. We hope that this process proves to be a useful roadmap for collaborations at other institutions.

Process

The long-term goal of the VCU team is to create and grow an enduring structure to provide a network of connections between the mathematics concepts and methods and the engineering or other partner discipline applications. The foundation for this structure so far has grown into regular conversations, common exam questions, and exemplar problems to bolster curriculum development in differential equations. The current initiative towards discovering and identifying ways to improve knowledge transfer has led to the start of an adaptable document that will provide a mapping of mathematical terms and processes to their engineering counterparts, as well as a comparative mapping of cross-disciplinary engineering terms and methods. This document will provide a latitudinal and longitudinal equivalency matrix that will aid students in making connections between similar concepts across different subject areas with mathematics serving as the common factor and will continue to grow over time as the VCU team maintains interactions with engineering and science faculty.

The students are engaged in the process through activities in both mathematics and engineering classes that ask them to compare the same mathematical construct through the lens of a variety of applications, discover their common factors, and juxtapose the methods, solutions, and outcomes in each case analyzed. Students learn that mathematics provides an "agnostic" solution and engineers provide the application-specific interpretation, aiding in building up the students' critical thinking and design skills. Additionally, the development of an adaptable document is useful for sustaining the collaboration by using its periodic review to drive systematic collaborative efforts. The specific examples of knowledge transfer described below include some ways in which students have already become part of the process both within and extracurricular to the course assessments.

Technical Examples

As students progress in more advanced mathematics courses, particularly courses such as Differential Equations (DE), they are given opportunities to connect mathematics with practical applications. This often requires translating the description of a physical problem into the corresponding mathematical construct. This can be challenging if different expressions, notations, and/or conventions are used in mathematics vs partner disciplines. We present examples of these collected over the last few years and describe efforts to bridge this gap.

Notation

Several mathematics constructs have multiple types of acceptable notation but there are instances where one is used more in mathematics contexts and another in engineering. One fundamental example of this is the notation used for derivatives. The Leibniz notation dy/dx is ubiquitous and perhaps most useful because it clearly identifies the independent variable. Mathematicians also use the more compact Lagrange or "prime" notation, $y'(x)$ or sometimes abbreviated as simply y'. Less common in mathematics is Newton or "dot" notation $\dot{y}$, often used to indicate derivatives with respect to time and therefore more prevalent in applied disciplines such as engineering and physics. It is reasonable to introduce all types of notations in a mathematics class and indicate the context in which they will be seen. Similarly, Leibniz notation is often used for partial derivatives as is the "subscript" notation, but the order in which derivatives are taken is indicated differently for each style and should be reiterated for novice students.

The imaginary unit or imaginary number, that is the root of the equation $x^2 + 1 = 0$, is conventionally referred to as i in mathematics. This becomes a conflict in disciplines such as electrical and control systems engineering where i is used to denote current. In these cases, j is used instead. It is important then to clarify to students in a mathematics class that when dealing with complex numbers i is the $\sqrt{-1}$, but in a circuit application i is current, and j may be needed to represent $\sqrt{-1}$. Another example of notation conflict is dealing with units. Mathematics majors focused on theoretical mathematics may not need to care about units, and there may not be as much emphasis on them in earlier classes. In application problems, however, they are a necessary component of the quantitative solution. To complicate matters, one common DE textbook used at VCU frequently uses imperial or United States (US) units which would seem logical in a US university course, but recently partner discipline faculty have clarified they work exclusively with SI units. This simple knowledge sharing between faculty has aided in streamlining instruction in recent years.

Terminology

Application-focused courses have several examples of mathematical terms describing processes that have different terms in other related disciplines. It is imperative that students can recognize these and "translate" between them to make the connections required to solve real-world problems. Perhaps the most basic of these in continuous mathematics is describing the *derivative* as both the *tangent slope* and the *rate of change*. Students often come out of calculus having memorized derivative formulas without retaining an understanding of what a derivative is both mathematically and practically. A typical modeling problem will often state something about the rate of change (growth, decay) of a quantity that has certain behavior, which should immediately be a prompt to write down a derivative but has still proven to be a challenge for our typical students in DE and partner discipline courses.

Coordinate systems have multiple naming conventions that can conflate terminology between disciplines. The VCU introductory DE course operates with the standard Cartesian coordinate system, but discipline-specific courses that draw on multi-variable calculus to develop partial differential equations draw upon spatial coordinate knowledge. As an example, cylindrical coordinate systems are often used to represent a 3-D cylindrical domain in fewer spatial dimensions by exploiting symmetry. The height or length down the center of the cylinder, or the axial coordinate, is also called the z coordinate. The distance from the z axis is called the radial distance or radius and can be denoted by r, ρ, or R, and the angular position around the cylinder is the angular coordinate or azimuth and can be denoted as either θ or ϕ. To further complicate coordinate system terminology, the symbols for theta and phi have two forms: θ or ϑ, and ϕ or φ correspondingly. When asked out of context if these are the same letters, over 80% of a junior-level engineering class voted “no”.

The cumulative effect of having to navigate through this variety of “standard” symbols and nomenclature can be intimidating to a new learner. It would be very helpful for someone in that situation to have access to a reference where conflicting terminology, symbols, and conventions are linked and defined in context.

Conceptual Examples

We have thus far presented examples of terminology and notation that can differ between mathematics and partner disciplines. With more advanced content, numerous mathematical concepts have a universal interpretation between disciplines but for multiple applications that are usually seen for the first time in DE, and so should be introduced with this in mind.

Translation

DE provides exposure to translating a physical problem into a mathematical model in conjunction with learning the tools for deriving solutions to differential equations. Students then further encounter more real-world modeling problems in their partner discipline courses involving the calculation of quantities based on known information like rates of change. As was done with *derivative* above, key phrases with direct mathematical meaning are discussed with students as part of a procedure for translation. For example, students learn that “the rate of growth of a population is proportional to the current population” translates to $dP/dt = kP$. A chart of typical “translations” encountered in modeling is shown in Table 1. As part of the team’s efforts to understand students’ ability to translate, a related set of terms, including some of those in Table 1, were given to DE students as an ungraded “quiz” to see if they could recognize them and give some sort of definition. Results were categorized post hoc by the team as theoretical, conceptual, or incorrect. The percentages of student responses appear in Table 2 in the Solutions section below. Some results were surprising; students had very low response rates for the term “transient”, even though they could conceptualize “steady state”. In addition, only 5% could provide a contextual example for “rate constant”.

A classic example of a translatable differential equation is the “mixing problem”, describing the change in the amount of salt in a saltwater tank as built up from a mass balance paradigm, i.e. “rate of change of quantity = rate in - rate out.” While this paradigm is a concrete way of understanding a change in an actual mass of something, it can also translate to living organisms in a closed environment or to non-STEM quantities, such as money. Thus, when presenting the theory of building a differential equation, it is advantageous to present the translation in multiple forms and describe multiple contexts in which it is used without necessarily solving the problem or going into detail about the application.

Solutions

The VCU team has observed that even the seemingly fundamental phrases “solution to differential equation” or “solve the differential equation” carry imprecise meanings for students, most of whom in earlier courses have only had to solve for variables that represent scalars. A solution to a differential equation is mathematically defined as a function defined on an interval

Table 1
Examples of Problem Statements, their Equivalent Mathematical Term, and Symbol Options

Problem Statements	Mathematical Term	Symbol Options
Is	Is equal to	$=$
Rate of change, Growth / decay	First-order derivative	$y', \dot{y}, \frac{dy}{dx}, Dy$
Rate of acceleration, deceleration	Second-order derivative	$y'', \ddot{y}, \frac{d^2y}{dx^2}, D^2y$
Is proportional to	Varies directly with	$y \propto x, y = kx$
Has an n −order dependence		$y = a_n x^n + a_{n-1}x^{n-1} + \cdots + a_0$
Has an exponential dependence		$y = Ae^{kx}$
Difference, sum	Minus, plus	$-, +$
Interaction, ratio	Multiplied (times), Divided by	$\times$ or $\cdot$; $\div$ or $/$
Half-life	The time at which the value of y is equal to 0.5 its original value	$y(t_{0.5}) = 0.5y(t = 0) = 0.5y_0$
Double, triple		$y(t) = 2y_0, y(t) = 3y_0$

that reduces a differential equation to an identity, but practically it describes the time or spatially dependent behavior of a quantity under study. Since students traditionally begin solving differential equations in the DE course before having physical context this connection can be missing early on. Later in the course in an introductory modeling scenario, students may be asked to find the "equation of motion", meaning the solution to a differential equation describing the motion of a system as a function of time. It is critical for an instructor to explicitly lead students to a comprehensive understanding of what a solution is.

While most introductory DE courses focus on applications and behavior of solutions, they also allocate time to explore when a unique solution to an initial value problem exists. The first step is understanding that an *initial value problem* comprises a differential equation and the initial condition together. Applying a procedure to solve a differential equation does not demonstrate mastery, but instead, a practitioner must also be concerned with if and how the solution dynamics relate to a given data point. Most students have rarely had to consider if there is an answer to the problem they are asked to solve, or if there may be more than one valid answer. The closest analogy they may have encountered is solving a 2×2 system of linear equations where it's clear that a unique solution represents a point of intersection, no solution is parallel lines, and the existence of infinitely many solutions means the lines are the same. This analogy put forth in DE classes in recent years at VCU has helped students transfer their understanding to real engineering problems that might offer more than one possible mathematical solution; the role of the engineer is to apply further knowledge of the system dynamics to limit the solutions to one physically possible solution. The mathematics majors will find this theoretical treatment to be the foundation for future work. Meanwhile, the engineering majors will use their physical understanding of a system, including approximations and limitations, to ensure that a solution is possible or to discover that the model is inadequate for the case under consideration.

Table 2
Responses to Differential Equations Term Identification Quiz

Term	Student Response: Theoretical/Symbolic	Student Response: Conceptual	Student Response: Missing/Wrong
Derivative	81%	15%	3%
Rate of change	29%	40%	20%
Variable	63%	34%	1%
Parameter	5%	17%	77%
Transient	3%	12%	84%
Proportional	27%	25%	46%
Linear	41%	51%	6%
Steady state	5%	39%	55%
Homogeneous	20%	32%	46%
Forcing function	20%	12%	67%
Tangent	12%	63%	24%
Source	0%	31%	68%
Area under a curve	34%	53%	12%
Integral	60%	25%	13%
Equilibrium	1%	51%	46%
Mass balance	1%	10%	87%
Rate constant	25%	5%	68%

Note. The set of terms was provided to students as an ungraded DE class quiz to assess their ability to define them theoretically (symbolically) or conceptually. The table provides % that responded correctly to each term as well as % wrong or missing.

DE is one of the first courses where students gain experience translating the description of a solution from a mathematical expression to a graphical or visual representation. This is particularly useful for autonomous, or time-independent, first order differential equations for which representative solutions are easy to sketch with a direction field but may be more cumbersome to solve explicitly. Students explore qualitatively how solutions are related, how they are impacted by initial conditions and parameter values, and what long-term behavior looks like. Solutions to second-order constant coefficient initial conditions that represent the equation of motion similarly describe the observed behavior of the state quantity. For example, an underdamped system is pictured as the name describes, with the underdamped variable typically overshooting its steady state, establishing damped oscillations, and eventually settling into its steady state response. Students can change the physical coefficients in the problem (i.e., increase a damping coefficient to increase damping) and observe the change in behavior of a solution, made even more accessible by the appropriate use of technology. The skills for representation and interpretation of results are more easily transferred to partner discipline-specific courses with the foundation given in DE.

Further understanding and communication about the long-term solution of a dynamic system again leads to the use of multiple terms, meaning identical concepts from different perspectives. Specific to a time-dependent system, the *limit as time goes to infinity* and the *asymptotic* behavior both mathematically describe long-term behavior. Students fresh out of calculus may still be challenged by the notion of a limit and even an asymptote and therefore may not understand their practical implications, but should be able to transfer the idea of short-term vs long-term in time for greater understanding of the mathematical description. This distinction in an applied discipline however is often called *transient* vs *steady-state* with reference to a time-dependent system. The common DE text used at VCU introduces the latter terms as a foreshadowing for context that will be encountered by engineering and science majors. Furthermore, engineering students continue to conflate "transient" with "time-domain". This can be explained by two common practices in the engineering community: (i) the quickness with which an engineering curriculum proceeds, spending relatively little time discussing and demonstrating transient response and its importance, and (ii) the practice, in engineering simulators such as MultiSim, of using "transient" as a catch-all term to describe any time-domain solution.

Applications

As part of the SUMMIT-P partnership with engineering, the VCU DE course has recently transitioned to a greater focus on modeling, applications, and behavior of solutions as related to parameters. One beneficial consequence is familiarizing students with a variety of letters describing independent and dependent variables. For example, population growth, amount of radioactive decay, and attenuation of light intensity can all be described by the same form of a first order separable differential equation but typically describe the dependent variable with $\mathrm{P}, \mathrm{A}, \mathrm{I}$ respectively. Similarly, students learn that a typical mixing problem with constant inflow and proportional outflow has the same mathematical formulation as a description of drug metabolism with constant drug delivery and proportional metabolism, and so can be solved with the same tools though they would usually have different symbolic representations. Because a differential equation is usually solved symbolically to generalize for all possible values of variables and parameters, it is common to represent scalars and constants with representative letters such as "k" for a proportionality constant. Since students in differential equations are still novices with symbolic mathematics, the practice of modeling in this course is beneficial to understanding the meaning and purpose of a differential equation.

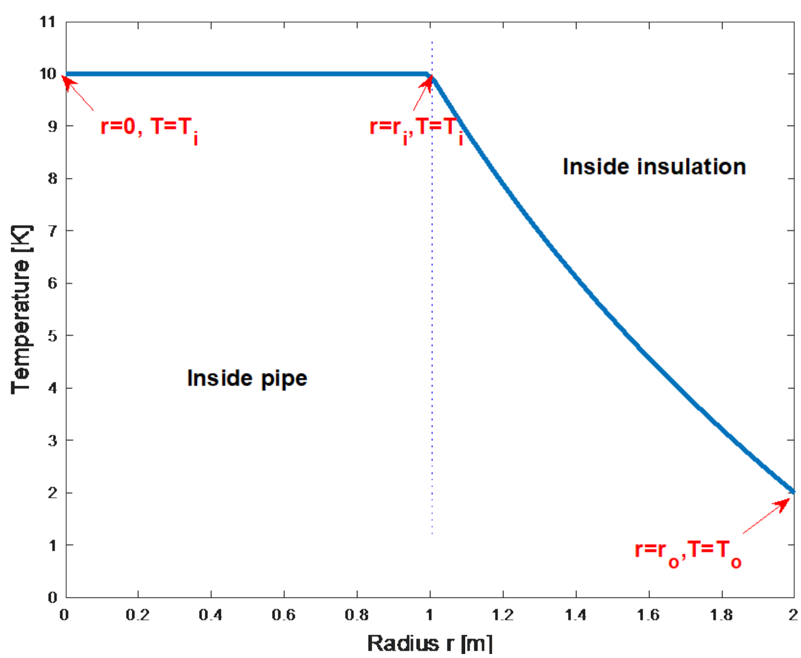
One classic example of a differential equation with analogs in multiple sciences that is given extensive attention in the VCU course is the second order spring-mass-dashpot (-damper) equation. This equation describing the displacement x of an attached mass is often derived in the class from balancing the forces of acceleration on the mass, the behavior of the spring, and any damping medium that resists motion. This equation has the advantage that its solution describes physical spring dynamics that are observable to the naked eye, and thus easily demonstrated in the classroom with accessible physics equipment. Concepts such as the equation of motion, damping, and forcing function then have real physical meaning that is immediately connected to the mathematical notation. In DE at VCU with many electrical and computer engineering majors, this second order differential equation is also presented as its circuit analog, a voltage balance on a Resistor-Inductor-Capacitor (R-L-C) circuit determined by Kirchhoff's voltage law (KVL). In this differential equation, the state variable is charge q, the mathematical equivalents of acceleration, damping, and spring forces are analogous to the voltage relationships for the inductance L, resistance R, and (the reciprocal of) the capacitance C correspondingly, and system dynamics are forced by an input voltage. The third hydraulic analog using the same differential equation applies to fluid flow induced by a pressure potential, including flows in physiology and biology, so it is of interest to our biomedical and chemical engineering students. It is not treated as extensively in the VCU course as in the prior two but even its brief mention in the course shows students the ubiquitous and transferable nature of this differential equation and its potential uses in future applications in partner disciplines.

Vignette – Virginia Commonwealth University

As part of the earlier collaborative work, the VCU team asked the broader engineering faculty to identify and submit typical course assignments that use introductory differential equations. These were compiled into a catalog of differential equations-focused application problems for the mathematics faculty to be able to introduce in DE to aid in knowledge transfer. The example shared here from mechanical engineering describes heat loss from a cylindrical pipe under steady state conditions (Filippas et al., in press) (see Figure 1 for a typical solution). In its original engineering-focused format, it was assumed that students already understood the heat transfer context and had passed the pre-requisite DE course being discussed here. Attention is given to using symmetry to transform a 3-D problem into a 1-D problem with dependence only on radius. The VCU team expanded on the details of heat transfer, set up the appropriate differential equation for the students, and made the mathematical questions more explicit in the first adaptation of this problem specifically for the DE course itself. For a particular implementation in Fall 2021, one mathematics professor modified it further to guide the students towards creating the differential equation themselves, plus added reasonable values for calculating and graphing a typical solution. In this version given to students in DE as classwork, only 2 of 7 questions directly used DE content – solving symbolically with separation of variables and finding the particular solution with a general initial condition. However, providing context around the DE content helps address issues discussed earlier such as like notation, terminology, and translation which smooths the knowledge transfer to future engineering courses. In fact, engineering students are often excited when this problem appears because they recognize the engineering style of the problem and have, on occasion, pulled out an engineering textbook to show the professor a similar problem!

Figure 1

Graph of Temperature for Steady-state Heat Loss through a Cylindrical Pipe Problem



Note. This problem is a 1-D modification of a 3-D physical scenario simplified by using radial symmetry.

Vignette – Norfolk State University

Another member of the SUMMIT-P consortium, Norfolk State University, also set up a teaching collaboration between their mathematics and engineering departments. Their team created several teaching modules on various engineering applications of differential equations. One of the most successful projects explores the application of a system of two second-order differential equations in the context of wireless power transfer (WPT) such as that which might be used for a smartphone charging pad. In this system, the two equations represent the transmitter circuit and the receiver circuit in the WPT. With R_1, L_1, C_1 *as the RLC components of the transmitting circuit of the WPT and* R_2, L_2, C_2 *as the RLC components of the receiving circuit of the WPT,* M *as the mutual inductance coupling the transmitting and the receiving circuits, and* $V(t)$ *as the input sinusoidal voltage source, a simplified system of equations that govern a WPT is given by*

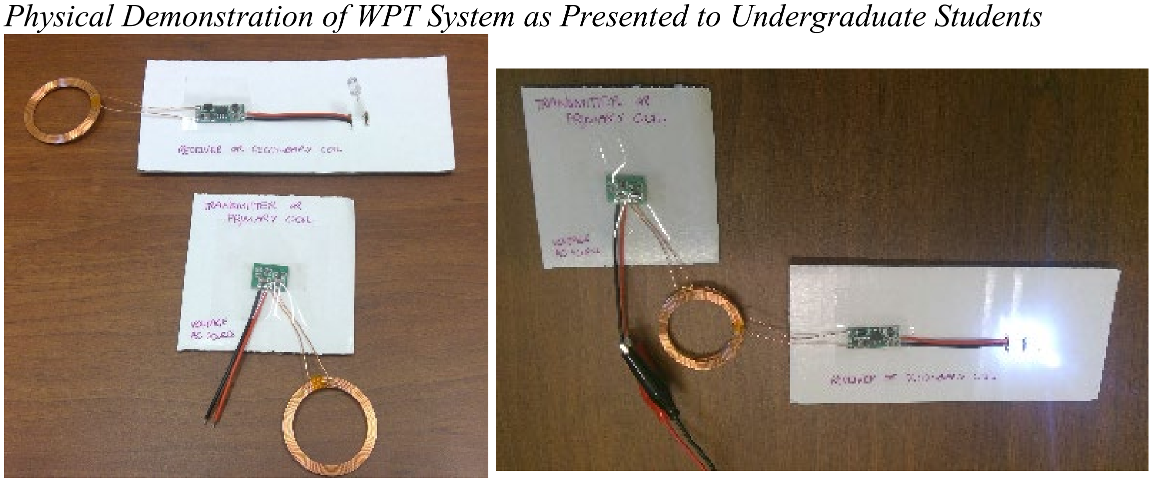
$$\begin{cases} L_1 i_1'' + M i_2'' + R_1 i_1' + \frac{1}{C_1} i_1 = V'(t) \\ L_2 i_2'' + M i_1'' + R_2 i_2' + \frac{1}{C_2} i_2 = V'(t) \end{cases}.$$

Here, the dependent variables are the currents $i_1(t)$ *and* $i_2(t)$ *of the transmitting and the receiving circuits, respectively.*

This teaching module is currently embedded in the latter part of a first course in differential equations. The module includes the physical demonstration pictured in Figure 2. Panel (a) shows the receiver circuit (secondary coil) has a LED that is initially off. When the transmitter circuit (or primary coil) is coupled to the receiver circuit, electrical power is wirelessly transferred so that the LED lights up as seen in panel (b). Students see that an electrical circuit can be viewed from a mathematical perspective so that they can transfer their mathematical skills to the engineering classroom. Faculty emphasize that each component in the circuit represents a term in the differential equation. In this way, students see a tangible example of an engineering application outside an engineering laboratory and learn that analyzing a circuit is tantamount to investigating the solutions to a differential equation.

Figure 2

Physical Demonstration of WPT System as Presented to Undergraduate Students



(a) (b)

Note. (a) Receiver's LED is off. (b) Primary coil (transmitter circuit) is coupled to the secondary coil, which turns the LED on.

Students' responses both from class and extracurricular demonstrations have been positive, even among students who have not formally studied differential equations. The tangible and portable demonstration facilitates the knowledge transfer between the differential equations and engineering concepts. At the end of each presentation, students leave with a version of the following mantra, "Every RLC (resistance-impedance-compliance) circuit is a higher-order differential equation with constant coefficients."

Cognitive Load Analysis

Having identified knowledge transfer as a nontrivial component of student learning of differential equations concepts, the VCU team questioned whether the instructors of discipline-specific courses account for the added cognitive load placed on students when solving a problem. For many engineering students, such courses will be their first extensive exposure to context requiring more than just being provided with a differential equation and the corresponding initial, final, or boundary conditions. As students then proceed through an engineering curriculum beyond differential equations, it is often the case that collateral requirements are needed to derive the appropriate differential equation for the application, use the problem description to derive the initial or final conditions, and, finally, to solve the equation and interpret the answer in the context of the specific problem. While the mathematics has not changed, students are required to perform a different set of cognitive tasks in the partner discipline than they are required to do in a mathematics course.

Cognitive Load Map

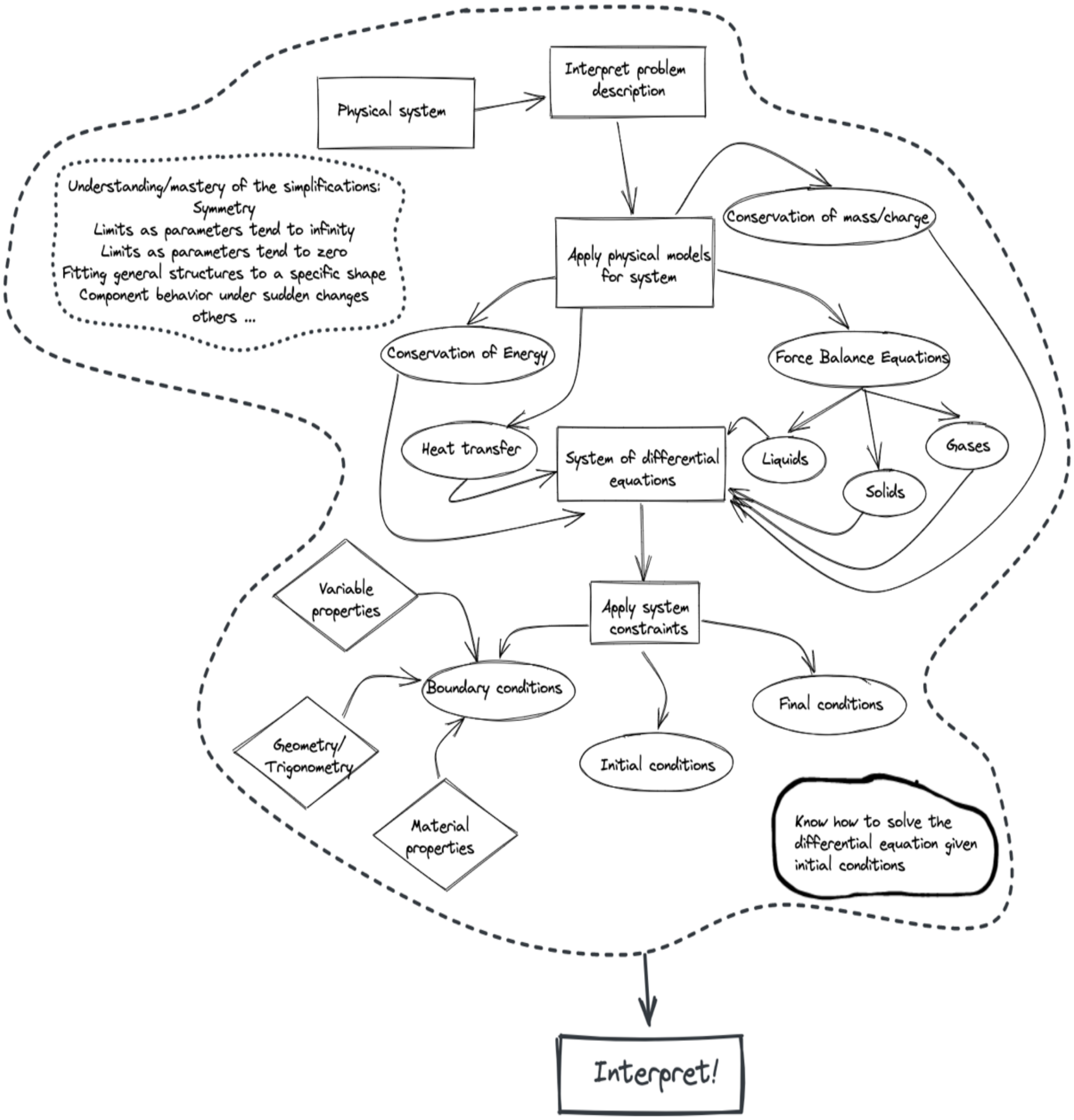
Figure 3 is an example of the knowledge, skills, and intuition an engineering student needs to develop when they are faced with a problem requiring the derivation and solution to a differential equation. The variety of naming conventions and increased complexity of the solution (e.g., being provided initial or final conditions vs having to derive them) is challenging for students who already have trouble seeing all the connections between their mathematics and engineering courses, making it even more important to show how the underlying mathematics is consistent between courses and disciplines. Therefore, it is important to maintain a reasonable cognitive load as the students move from the introductory level, agnostic mathematics course to the science and engineering courses that address problems of increasing complexity. For example, the modeling of a solution through the $e^{\alpha t}$ function is applied in introductory circuits, signals, and systems to introduce students to the transient response, but the $e^{j\omega t}$ function is used to solve more complex problems by implementing phasors in the frequency domain and is typically used to define the steady-state response of a system. Students need to move through these concepts in stages, with a strategic review of fundamental material and intentional linking of prior knowledge to current learning objectives. The weight of the accumulated cognitive load further motivates the creation of an adaptable document that not only links the mathematics to the science and engineering courses, but also the science and engineering courses to each other.

Example of Accumulated Cognitive Load

The challenge of transference of knowledge amplified by the accumulated cognitive load is illustrated here with a set of problems that are mathematically simple but require greater

Figure 3

Mind Map of Differential Equations in an Engineering Course



Note. The mind map demonstrates the actual complexity a student faces when solving a differential equation in an engineering course. Solving the equation itself comprises only a portion of the degree of mastery required.

engineering-specific sophisticated thinking by the students. In this example, a Resistor-Conductor (R-C) circuit and a Resistor-Inductor (R-L) circuit as shown in Figure 4 are described by the same form of a differential equation but differ significantly in the engineering concepts the students need to master in order to set up and solve these equations.

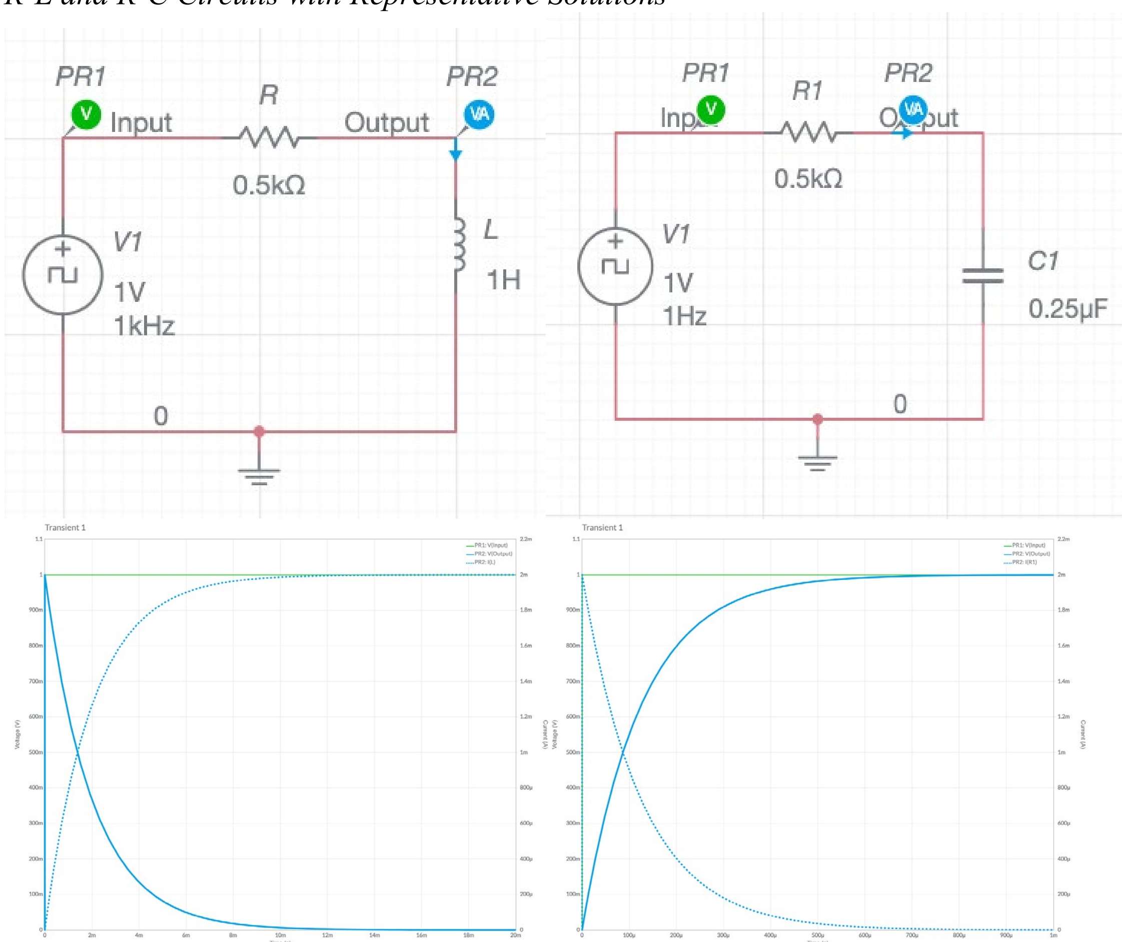
Both circuits in Figure 4 are described by a differential equation of the form $dx/dt + \alpha i = x_s(t)$ with $x(t)$ as current i, $x_s(t)$ relating to a constant or time-varying voltage source, and parameter α relating to a time constant characterizing the circuit's response. Students need to apply KVL to derive this equation using the same components discussed previously in the Applications section of this paper. In the case of the R-L circuit, $\alpha = \alpha_{RL} = -R/L$, while in the

R-C circuit, $\alpha = \alpha_{RC} = -1/RC$. Furthermore, in the above circuits, the square wave is simulating the action of a switch; i.e., at time $t = 0^{-}$ $(t < 0)$, the switch is open, and all initial conditions are zero. At $t = 0^{+}$ $(t > 0)$, the switch closes, connecting the source to R and L or R and C, respectively.

Mathematically this is a simple first order non-homogenous differential equation, for which there are standard solution techniques learned in an introductory DE course. Multiple challenges arise beyond the mathematics, however, including identifying equation components in the context of the engineering application and having a piecewise forcing function as the source. To solve this differential equation, students need to first understand that the square wave voltage source is acting as a direct current (constant) at all times except for at time $t = 0$. Solving the equation as a "zero-input response" is analogous to finding its homogeneous solution, giving the characteristic equation and roots λ. Thus, the zero-input response is found to be $i(t) = Ae^{\lambda t} + B$, and the students obtain $\lambda = -R/L$ for the R-L circuit and $\lambda = -1/RC$ for the R-C circuit.

Figure 4

R-L and R-C Circuits with Representative Solutions



Note. Both circuits are described by a differential equation of the form $\frac{dx}{dt} + \alpha x(t) = bx_s(t)$.

Left: R-L circuit (top) and solution $i_L(t)$ (bottom) to the DE $\frac{di}{dt} + \left(\frac{R}{L}\right) i = \frac{v_s}{L}$. In the solution for $i_L(t)$, $\lim_{t\to\infty}(i(t)) = \frac{v_s}{R}$ and $\lim_{t\to\infty}(v_L(t)) = 0$. Note the sharp increase of $v_L = v_s(0^{+})$ at time $t = 0^{+}$and the asymptotic decay to zero as $t\to\infty$.

Right: R-C circuit (top) and solution $i_c(t)$ (bottom) to the DE $\frac{di}{dt} + \frac{1}{RC} i = \frac{1}{R}\frac{dv_s}{dt}$. Similar to the R-L circuit, the solution graph shows $i_C(0^{+})$ increasing sharply and going asymptotically to zero.

Students need to subsequently develop the initial conditions from the engineering context, again using KVL as well as their knowledge of the physical limitations of the devices in the circuit. For example, the current through the inductor and the voltage across the capacitor cannot change instantaneously, but KVL has to be satisfied every time, t. Thus, for the R-L circuit, $v_L(0^+) = v_s(0^+) = Ldi/dt|_{t=0^+}$; so, $di/dt|_{0^+} = v_s(0^+)/L$. Similarly, for the R-C circuit, $v_C(0^+) = 0$, so $v_R = i(0^+)R = v_s(0^+) \Leftrightarrow i(0^+) = v_s(0^+)/R$. Using these context-specific initial conditions students derive the final solutions: for the R-L circuit, $i_L(t) = (v_s/R)(1 - e^{-(L/R)t})$ and for the R-C circuit, $i_C(t) = (v_s/R)e^{-t/(RC)}$.

Fully completing the problem requires that students interpret the solution to understand how each component will respond. The terms L/R for the inductor and RC for the capacitor are considered the "time constants" with units of time. This makes the terms $(R/L)t$ and $t/(RC)$ unitless and therefore consistent with the exponential function. Students observe how units are derived from the nature of the components, and the solution, derived from the laws governing these components, naturally leads to the correct units. Furthermore, the R-L circuit solution $i_L(t)$ in Figure 4 (left) shows a sharp increase of $v_L = v_s(0^+)$ at time $t = 0^+$and an asymptotic decay to zero as $t \rightarrow \infty$, whereas the R-C circuit solution $i_c(t)$ (right) shows $i_C(0^+)$ increasing sharply and going asymptotically to zero.

These types of problems use the natural, unforced, or autonomous response, and refer to systems that are not subjected to a continuously changing signal. As such, they might become activated by a sudden change – modeled as initial conditions – but will revert asymptotically to their natural state. Also, this problem deals exclusively with discrete components, so students need to track only one independent variable. More typical and realistic problems deal with changes in space and time, and do not generally have closed-form solutions. This means that students must understand the physical laws governing the system, start from an accurate model for its behavior, but then use symmetry or specific problem simplifications (solution along an axis of symmetry, etc.) to be able to solve the differential equation for a specific case.

Conclusions

We have presented several examples of disparate ways terminology, concepts, and applications are presented in mathematics and engineering courses as well as the added cognitive load placed on new learners when they are required to apply mathematics concepts to complex problems. These challenges possibly serve to disengage students' understanding of the role mathematics plays in their chosen field and the power it has to aid in the systematic and effective design of innovative solutions to engineering problems. It is important, therefore, to continue the intentional links between mathematics and engineering in the engineering courses, through the review of concepts but also through the continuous application of these concepts in problems of gradually increasing complexity.

It behooves faculty, therefore, to address classes that would benefit from the merging of mathematics and discipline-specific terminology, not with the question of whether the course can be taught without this knowledge, but rather as an opportunity for further student engagement. Other successful models include review sessions either on an as-needed basis or a "mathematics bootcamp" at the beginning of the course to review and align terminology. This, however, cannot replace the systematic application of increasingly complex mathematics skills in all coursework and an in-depth discussion of the information these equations provide about the behavior of the systems under review. Regardless of the approach, clearly the only way forward is with good communication between the faculty.

Finally, each mathematics course and partner discipline pairing will have specific concerns but providing the time and opportunity for students to study the beauty and utility of mathematics in the solution to a multitude of everyday challenges that impact the human condition, and to build intentional links between mathematics and their specific field of interest will enhance student learning and improve both student and instructor engagement.

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Using an Interdisciplinary Case Study to Incorporate Quantitative Reasoning in Social Work, Nursing, and Mathematics

Elizabeth Post
Ferris State University
ElizabethPost@ferris.edu

Mischelle Stone
Ferris State University
MischelleStone@ferris.edu

Lauren Cavner Williams
Ferris State University
LaurenCavnerWilliams@ferris.edu

Mary Beaudry
Ferris State University
MaryBeaudry@ferris.edu

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Abstract

Through the national consortium, SUMMIT-P, Ferris State University faculty collaborated to develop and scaffold mathematics and quantitative reasoning across disciplines to reduce math anxiety. Participants in this collaborative group included faculty from social work, nursing, and mathematics who developed a case study on a Hurricane Katrina scenario that necessitated calculating the need for emergency shelter, water, food, and medicine, and as a response to the potential for a Malaria outbreak. This particular case study allowed faculty to use the lens of social justice to teach mathematical concepts and provided an avenue for nursing and social work students to engage in mathematics through a case study germane to their profession. This article discusses the process of developing this case study and focuses on the successes and challenges faculty and students faced while the parts of the case study were implemented in the varied disciplines. This discussion also includes sidebar contributions from faculty at other SUMMIT-P institutions who have engaged in similar cross-disciplinary collaborations.

Keywords

quantitative reasoning, mathematics, social work, nursing, case study, interdisciplinary, education

General math anxiety is “a state commonly described as approaching mathematics with trepidation due to related feelings of weakness, dependency, and frustration” (Hekimoglu & Kittrell, 2010, p. 301). There can be many reasons for this state of trepidation, among them the transfer of mathematics anxiety from parent to child (Maloney et al., 2015). In addition to parents, teachers also can influence students' math anxiety, whether it is through imparting their own attitude toward the subject, or through their choice of instructional methods. For example, when procedural, rather than applicable, learning becomes the focus in classrooms, “these policies have produced students that rely more on rote memorization and have increased the level of anxiety in young children by making mathematics a high-risk activity” (Geist, 2010, p. 25). Further, when compared to men, women tend to have greater levels of math anxiety (Hart & Ganley, 2019).

Math anxiety can be an obstacle for students seeking a degree, as mathematics is often positioned as a gatekeeper subject. In addition, “students with math anxiety will likely avoid careers that require math” (Henrich & Lee, 2011, p. 1). The paradox here is that many, if not most, careers involve some form of quantitative reasoning. Often, students do not understand how and why they will use quantitative reasoning in their careers after college (Davis & Mirick, 2015), so it is important to introduce these concepts via applications that are relevant to the students. With these goals in mind, the national consortium, Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnerships (SUMMIT-P) engaged faculty from 14 institutions to improve lower-level mathematics courses through collaboration with other disciplines. This article discusses general math anxiety across the disciplines of mathematics, social work, and nursing, best practices to address general math anxiety, and the development of a Faculty Learning Community (FLC) at Ferris State University (Ferris) to improve mathematics and quantitative reasoning courses through the development of an interdisciplinary case study.

Math Anxiety in Quantitative Reasoning Courses

It is not uncommon for students who enter a college mathematics or quantitative reasoning course to express anxiety about mathematics. This anxiety can stem from what the students describe as negative or stressful experiences they previously had with the subject. These experiences may have come from one of the following common causes: “having an insensitive or incompetent math teacher in the past, student fear of failure or a sense of inadequacy, inability to handle frustration, poor pre-college math preparation, and low math achievement” (Henrich & Lee, 2011, p. 1). In addition, some students who enter college later in life express anxiety regarding mathematics because they have not interacted with the subject in years. Support for students in mathematics and quantitative reasoning courses is important because of the status of mathematics as a gatekeeper subject (Thiel et al., 2008), and because having math anxiety “may affect students’ success in their higher education studies” (Núñez-Peña et al., 2013, p. 49). Helping students succeed in their mathematics courses is not only important while enrolled in the courses themselves, but also to help them achieve their goal of graduating from college.

Math anxiety is expressed by students in nearly all disciplines. For example, it is not unusual to hear a social work student say they are “just not a math person” or are “more clinical” in their orientation. The first empirical research conducted on how this phenomenon manifests in the social sciences was done by DeCesare (2007), who surveyed sociology students about their math anxiety. In this study, students experiencing math anxiety also showed higher levels of test anxiety. Conversely, students who had previously taken a statistics course reported lower anxiety levels. Davis and Mirick (2015) surveyed graduate social work students to delve deeper into this phenomenon and to better understand students' attitudes and beliefs about statistics. They found that after having taken a statistics course, students both perceived statistics as important in the profession and indeed, used it in the field of social work in their practicum experience. Quantitative reasoning and mathematics are integral to social work. To be able to use evidence-based practice, social work practitioners must be able to read and critically evaluate research studies. They must also be able to evaluate their own work with individual clients as well as their work at the community level. Further, practitioners must be able to evaluate if an individual client is meeting his or her treatment goals, as well as evaluate whether an entire program is effective.

Math anxiety is also common in nursing. In nursing education, educators find that students have elevated levels of anxiety with high-stakes testing and clinical settings where demonstration of mathematics skills is crucial. In clinical settings such as the intensive care unit (ICU), students can display excessive anxiety which impedes clear and critical thinking (Hopkins, 2019). Patient care involves assessing, medicating, treating, and educating patients. To accomplish these tasks, a nurse must demonstrate proficiency in mathematics. When a dose of medication is incorrectly calculated, patient lives are at risk. Addressing math anxiety in both classroom and clinical settings is necessary to provide a learning environment that leads to appropriate patient care.

Math anxiety is even present at STEM Universities. Faculty at Emory Riddle Aeronautics University (ERAU), a widely respected STEM-focused university, noted their own experience with teaching students who have math anxiety:

> *Even at our STEM-focused institution, the non-traditionally aged students of the Worldwide Campus have a great deal of math anxiety. Not all of our students need calculus to succeed in aviation and aerospace careers, but every student everywhere needs to skillfully approach quantitative information in their lives. Coursework that addresses the breadth of mathematics – rather than the climb to calculus – is the goal of our quantitative reasoning courses.*

Best Practices to Overcome Math Anxiety

There are established best practices to overcome math anxiety in mathematics and quantitative reasoning courses and other disciplines. One of these practices is to have students complete a mathematics autobiography as a way to encourage students to reflect on their experiences with, and feelings about, mathematics and quantitative reasoning. This exercise can help students communicate their concerns early in the semester in an interaction with the instructor that the students do not find intimidating. This assignment could also help students organize their thoughts and feelings and they may come to a better understanding of themselves as a person and a learner. It can also help the instructor gain a better understanding of the students in the classroom. This exercise could be incorporated into courses across various curriculums, rather than offering it solely in just one or two required mathematics courses.

Another best practice includes continued exposure to quantitative reasoning, rather than teaching it in one discrete course. Condron, Becker, and Bzhetaj (2018) found that continued exposure to quantitative reasoning instruction helps to reduce math anxiety. They surveyed social work students about general math anxiety and provide a framework for incorporating quantitative reasoning across the curriculum. This includes beginning the semester with a review of mathematical concepts, explaining the importance of statistics in social work, and boosting students' confidence in statistics, including incorporating these analyses throughout the curriculum.

The use of interdisciplinary education to apply quantitative reasoning across the disciplines is another best practice for reducing math anxiety. In this practice, mathematical concepts are introduced in quantitative reasoning courses and reiterated in courses related to the student's field of study. Thus, the student has exposure to real-world applications. At Ferris, faculty had the opportunity to do just this through the SUMMIT-P project.

Interdisciplinary Collaboration – Establishing a Faculty Learning Community

The FLC at Ferris resulted, in large part, from the Curriculum Foundations (CF) Project, a comprehensive review of undergraduate mathematics programs from 1999 to 2007 (see Ganter & Barker, 2004; Ganter & Haver, 2011). The CF project conducted several workshops to help mathematics faculty gather information from 22 partner disciplines. Recommendations from the CF Project led to the creation of SUMMIT-P, a multi-institutional project that brought together numerous colleges and universities with the goal of creating interdisciplinary initiatives to improve student learning. One of these initiatives was the development of Faculty Learning Communities (FLCs).

To develop the FLC at Ferris, faculty from the local SUMMIT-P project team developed and submitted a proposal to the Faculty Center for Teaching and Learning (FCTL) at the university. The proposal was evaluated against predefined criteria, including how it aligned with the overall values of the FCTL, the measurability of outcomes, and the presence of an assessment plan. Following approval, the project team began to plan for the selection of faculty and the training itself. The year-long FLC began in August 2018, and the SUMMIT-P project team members served as facilitators of the FLC. The structure of the FLC was an outcome of faculty from the partner disciplines of mathematics, social work, and nursing coming together to engage in active collaboration to develop a curricular approach to enhance the teaching and learning of mathematics and quantitative reasoning. To select faculty members, a call went out to the individual departments letting them know that the project was being developed. Faculty then contacted the facilitators to express their interest. Faculty participating in the FLC were provided with professional development funds of $1,200 at the conclusion of their participation over the one-year period.

At the beginning of the FLC, all of the faculty who volunteered to participate were divided into interdisciplinary teams. Each time was comprised of a faculty member from mathematics, social work, and nursing. All FLC members met approximately every three weeks. Early on, the teams focused on identifying common mathematics and qualitative reasoning concepts that were embedded in their discipline-specific courses. The identification of these common concepts was designed to reduce the barriers that prevented students from carrying quantitative reasoning concepts forward into their respective majors, and to develop cross-disciplinary concepts and context that faculty could embed into each of the partner disciplines. The FLC interdisciplinary collaborative structure turned out to be relatively common among participants at the various SUMMIT-P institutions. This is illustrated in the description below of the collaborative structure provided by participating faculty at Lee University.

Vignette – Lee University

At Lee University a FLC initially started between the Departments of Mathematical Sciences; Behavioral and Social Sciences; Natural Sciences; and Early Childhood, Elementary, and Special Education. Faculty from the non-mathematical department disciplines consulted the CF project publication Voices of the Partner Disciplines (Ganter & Barker, 2004), for discipline-specific recommendations. Each partner discipline faculty shared the recommendations with their respective department to choose the ones that best suit their needs. Through several meetings and fish bowl activities, the faculty were able to map their discipline needs with the syllabi of the targeted mathematics courses. The recommendations were specifically for introductory courses: Algebra for Calculus, Introduction to Statistics, College Algebra, Concepts of Mathematics I, and Concepts of Mathematics II.

This initial collaboration resulted in a better understanding of each other's discipline, the realization of the different language used in each discipline, and the curriculum expectations of each discipline. From this point, the FLC was expanded to include other faculty from the collaborating departments. The discussions took the form of fishbowl activities or meetings with faculty from individual departments. Ideas for interventions were discussed and wish lists were created by the partner disciplines. The result of these collaborations has been the creation and implementation of several discipline-specific interventions in the above courses. Manipulatives were introduced, for the first time, in Concepts of Mathematics I and II, and Introduction to Statistics, and the creation of a collaborative environment between the different departments thus began breaking down discipline-specific silos in academia and increasing camaraderie among participants.

The Work of the Ferris FLC

One of the major goals of the FLC at Ferris was to confront the fragmented approach to teaching and learning that so frequently results in a student experience that lacks relevance and coherence across disciplines. Even though faculty are often incentivized to experiment with a variety of pedagogical strategies to enhance student learning, little has been done to encourage them to cross academic boundaries in order to collaborate in curricular reform (Bishop et al., 2020). Bringing faculty together toward this end is a rather large undertaking; however, without it, students are not likely to understand how to work collaboratively to solve real-world problems. The need to produce college graduates who are prepared to engage with real-world problems across their educational experience necessitates that faculty engage in cross-disciplinary efforts to provide opportunities for students to apply important concepts across disciplines. Nowhere is this more important than in mathematics and quantitative reasoning, which are often perceived by students as "stand-alone" disciplines unrelated to their major field of study. Even when students recognize that some mathematics or quantitative reasoning may be required in their specific discipline (such as nursing), they are often content to let computers perform the calculations for them. Students in specific disciplines apart from mathematics rarely understand or appreciate the extent to which the *context* for the calculations influences their application in the field. Bringing interdisciplinary faculty together in one space over an extended period of time to develop mathematical problems with application to real-world, discipline-specific situations was a primary goal of the FLC. This is consistent with the recommendations outlined in the CF Project (Ganter & Barker, 2004), which emphasizes the need to help students develop a conceptual understanding of mathematics as it relates to partner discipline needs.

One of the goals for the participants in the Ferris FLC was to reduce the rates of grades D, F, and W (withdrawal) among students in partner discipline courses. One of the previous challenges identified by the General Education task force at Ferris was the high number of students from all disciplines who received grades of D, F, or W in the lower-level mathematics and quantitative reasoning courses required to graduate. In discussing this issue at the start of the FLC, it became clear that all participants in both the partner disciplines and in mathematics could provide anecdotal data about fear and anxiety their students experienced relative to "passing math."

It was agreed by participants in the FLC that reducing this fear and anxiety would correlate to improved mathematics and quantitative reasoning scores, which would reduce D, F, W rates in the required mathematics classes for non-mathematics majors. One of the major challenges in accomplishing this reduction in fear and anxiety was to develop curricular activities where mathematical concepts necessary for different disciplines could be embedded in the discipline-specific courses. To accomplish this, a Case Scenario method was used. Participants decided to develop a case study on a Hurricane Katrina scenario which necessitated calculating the need for emergency shelter, water, food, and medicine, as well as a response to a potential for a malaria outbreak. This particular case study allowed faculty to use the lens of social justice to teach mathematical concepts in a mathematics course and provided an interesting avenue for nursing and social work students to engage in mathematics through a case study germane to their profession.

We used the following case scenario:

New Orleans was devastated by Hurricane Katrina in 2005 and has not yet fully recovered. There are significant social justice issues here as the areas initially affected were primarily in poor Black communities and have since taken a great deal of time to recover. The more affluent primarily white communities were less affected because they had the proper infrastructure and recovered faster because they had access to more resources. This city remains a hurricane hotspot.

Immersive experiences such as working on an interdisciplinary case study as described above shed new light on the value and contributions of other team members from different disciplines. Participating in the FLC led to an enhanced understanding by faculty of the context of how mathematical concepts and quantitative reasoning are identified and applied in the disciplines of social work and nursing.

The FLC group faced the challenge of developing and implementing assignments that maintained the integrity of the case study across disciplines. The group began with an analysis of the mathematics course and then used the course schedule to incorporate social work and nursing components. Each course introduced the same case study by showing a short video clip of a documentary and engaged students in a reflective discussion afterward. This introduced the case scenario and offered the framework for both quantitative reasoning and social justice.

Additionally, the group had considerable dialogue regarding how to scaffold quantitative reasoning into assignments. Ultimately, the group used the structure of the mathematics course to determine the scaffolding and then applied the framework to the social work and nursing courses. Scaffolding quantitative reasoning assignments was integral to the process.

The mathematics course provided a course pack of instructional materials to the mathematics students, which included instructional materials and assignments that made application of mathematics and quantitative reasoning concepts for all three disciplines. The course pack consisted of explorative activities that encouraged students to use a collaborative and inquiry-based approach to mathematical ideas rather than giving students content via lecture. Applications from nursing and social work were frequently used throughout the course pack. The application of mathematics to the partner disciplines was intentional and easily seen by students because of the examples included within assigned activities. For example, students interested in nursing were presented with examples involving patients' blood pressure or conversions for dosages of medication; students interested in social work could see the application of mathematics from the point of view of a homeless shelter, i.e., determining the change in the number of guests from one year to the next. In the case study scenario, each of the disciplines was intentionally built into the design. Social work was incorporated through ideas involving the finances of a shelter for displaced victims of the disaster, i.e. food, mortgage. Nursing was included through the use of determining proper dosages for antimalarial medication for adults, children, and infants, a likely result of the hurricane on the community, given the hot and humid summer climate in the region. It was through ideas like these that students could see the direct application of mathematics in their respective disciplines as well as the importance the subject has on real-world applications.

This case study was used in Introduction to Social Work to apply the social work values, ethical standards, and levels of practice (work with individuals on through community and policy work). This was designed to first engage students through the lens of social justice and then to introduce the importance of quantitative reasoning at an introductory level. Students learned how to read graphs representing the racial makeup of New Orleans before and after the hurricane. Additionally, students looked at maps representing the racial makeup and socioeconomic status in the city, before and after the hurricane (see Appendix A). Students also learned how to understand and compare percentages in order to see the disparate impact of Katrina on various populations. The class debriefed at the end of the lesson to connect the importance of quantitative reasoning and knowledge of disparate treatment of minoritized groups.

The case study was also used in the 200-level nursing course on role model development, which covers ethical decision-making and social justice issues. Further applications were introduced in the following semester in a 300-level course on nursing methods. This case study enabled students to practice simple ratio and proportion problems, dosage calculations using simple algebra, and engage in triage to determine who gets the medications and how much. The case study was modified here to include shortages of medications and food and ultimately the need for a shelter to house evacuees. The simplest of mathematics concepts were introduced in a nursing methods course, where calculations were taught and then applied to the case study. Students worked in small groups to solve the problems. Debriefing was essential if a calculation was missed; and discussions were held about the impact of medication shortages, correct doses, and the social justice issues that arose.

While the use of the case scenario across disciplines was conceived and implemented with little to no difficulty (largely due to the fact that all faculty involved in the FLC were stakeholders in the implementation of the scenario assignments in their own classes), a bigger challenge arose that required much more planning and cooperation from others outside the FLC. Specifically, it required that the advisors in each of the three disciplines plan how to enroll students from the three disciplines into specific sections of the mathematics courses. The advisors accomplished this by working collaboratively to establish sections of the mathematics courses in which students from the various disciplines were enrolled. This "cohort" of students moved together from one mathematics course to the next (e.g., Math 109 to Math 114), and included students from all three disciplines. This kept the students engaged with each other, professors, and the same material (albeit using different assignments) from course to course, with a goal of improving their ability to apply quantitative reasoning principles and concepts learned in one course to problems they encountered in the next course.

Recommendations for Other Institutions

As demonstrated by the research, math anxiety is mitigated through several recommended measures: (1) teaching students the application of mathematics and quantitative reasoning in their profession, (2) scaffolding mathematics throughout the curriculum rather than teaching it in one or two discrete courses, (3) evaluating student math anxiety at the beginning of the course, and (4) evaluating math skills at the beginning of the semester. Instructors should re-familiarize themselves with their own mathematics and quantitative reasoning skills, and be able to teach these skills to students in their respective disciplines. If faculty find that they are lacking in these skills, an FLC is recommended to focus on enhancing these skills for faculty in non-mathematics disciplines, and in our own experience, hindsight suggests that it would have been useful to have the mathematics faculty participating in the FLC provide "remedial" mathematics instruction on key concepts to faculty in the partner disciplines. Finally, and perhaps most importantly, it is necessary to get students to buy into the importance and application of mathematics and quantitative reasoning in their professional fields. By exploring math anxiety without judgement early in the course, students feel more supported in their attempts to learn the concepts and skills necessary to be successful in their mathematics courses. Using an interdisciplinary course that incorporates these concepts into their major field helps students see the value of mathematics and quantitative reasoning in their professions. When this happens, they are more likely to engage with the material because it is more meaningful to them.

Through our work with the FLC and our conversations between colleagues in social work, nursing, and mathematics disciplines, the case study scenario that emerged from the FLC collaboration served to bridge the application of mathematics and quantitative reasoning to real-world scenarios in social work and nursing. The hope is that this approach has lessened math anxiety, improved student understanding of mathematical and quantitative reasoning concepts, and reduced D, F, and W rates. Data is still being collected to determine if this result has been achieved. It is also hoped that these outcomes have enhanced the student goals of graduating and becoming successful in their profession of choice, which again, requires collecting data over the course of several years as students progress academically through their respective fields. Measuring the effectiveness of FLCs on student success is imperative to the sustainability of this pedagogical model for decreasing D, F, and W rates in mathematics courses. Further, the institutional changes need to take place that are necessary to overcome the discipline "silos" so prevalent on college campuses and to transform our views on the value of changing curricula to improve student learning.

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Author Note

Correspondence regarding this article should be addressed to Elizabeth Post, Department of Social Work, Ferris State University, 820 S. Campus Drive, Big Rapids, MI 49735 ElizabethPost@ferris.edu

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Appendix A

Math and the Partner Discipline Lesson Plan

SCWK 110 Introduction to Social Work

Social Work Values, Ethics and Levels of Practice Assignment

Learning objectives:

1. Demonstrate understanding and application of the social work values and ethical standards
2. Demonstrate understanding and application of the three tiers of social work practice
3. Demonstrate ability to read and understand a graph

New Orleans, LA, was devastated by Hurricane Katrina in 2005 and has not yet fully recovered. There are significant social justice issues here as the areas initially affected were primarily in poor Black communities and have since taken a great deal of time to recover. The more affluent primarily white communities were less affected because they had the proper infrastructure and recovered faster because they had access to more resources. This city remains in the hurricane path and is one area of the country that is most affected by hurricanes annually.

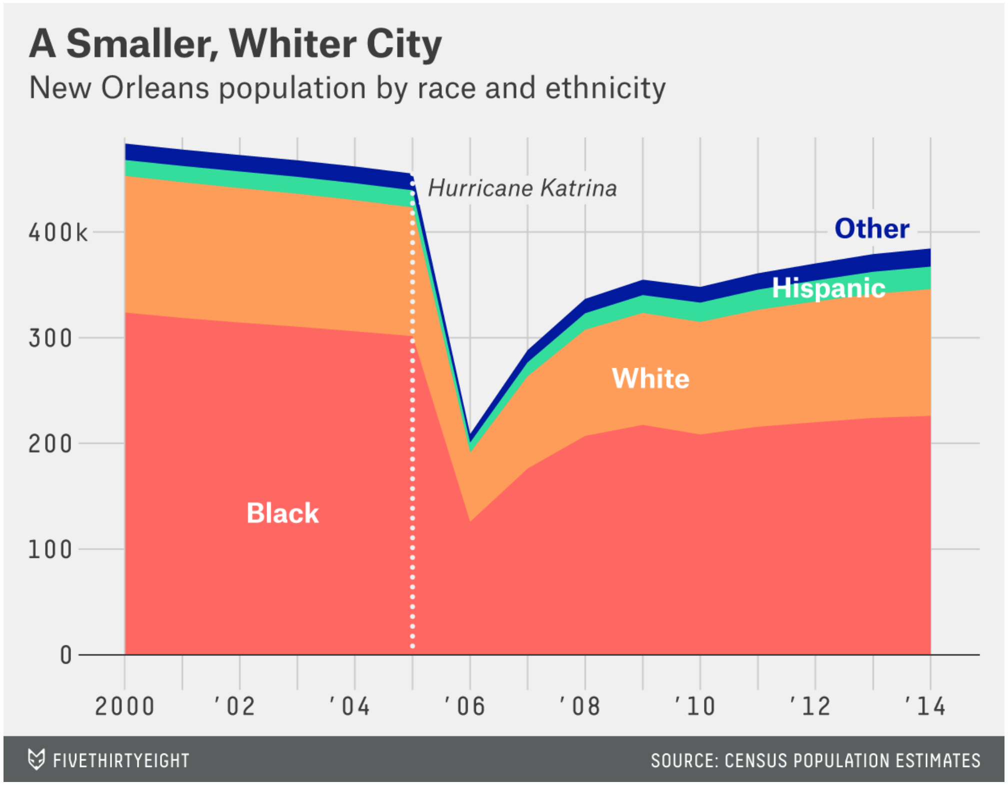
After watching *Trouble the Water* (2008), work in a small group to answer the following questions.

1. Identify and discuss what you observed in the film that relates to each of the six **values** of social work. Were these values upheld by those in power? Why or why not? Give concrete examples.
   a. Service
   b. Social justice
   c. Dignity and worth of the person
   d. Integrity
   e. Competence
   f. Importance of human relationships

2. If you were a social worker, tasked with helping the community recover, what ethical **standards** would you apply? Be specific here, including the specific ethical standard (i.e. Ethical responsibility to the client: 1.02 self-determination; 1.04 competence). Include as many as possible.

3. How were the different systems affected by the hurricane?
   a. Micro
   b. Mezzo
   c. Macro

4. Looking at the graph what do you notice about the population by race before and after the storm? What ethical standards would apply here? If you were to intervene, what tier of social work practice would you use?



5. Take some time to look at the racial **demographics** of New Orleans, LA in 2005. Now, compare these to 2017. Using the website: https://www.policymap.com/maps?i=9942151&nb=2&cb=12475&btd=18&period=2015&cx=-86.02858637207416&cy=39.76732647606186&cz=7

   What do you notice in general?

   What ethical issues do you notice if any?

6. Using the same website as listed in question 5, click on **Incomes and Spending**.

   What do you notice about the difference in incomes by race in 2005 as compared to 2017?

   What do you notice about the people in **poverty**?

   How is this different based on race?

   Websites: https://fivethirtyeight.com/features/katrina-washed-away-new-orleanss-black-middle-class/

Just in Time Mathematics Review for Accounting Students

Anneke Bart
Saint Louis University
anneke.bart@slu.edu

Michael May
Saint Louis University
mike.may@slu.edu

Debbie Pike
Saint Louis University
debbie.pike@slu.edu

Abstract

This paper describes the Just-in-Time Review developed for an undergraduate accounting course. The review materials cover five topics in algebra. Students take an online assessment, and online materials are made available to help students catch up in those areas where some review is recommended. This paper is a case study of the development and implementation of the Just-in-Time Review for an accounting course at Saint Louis University.

Keywords

review, algebra, accounting

https://doi.org/10.25891/say8-p705

Students taking an introduction to accounting course at the university level often struggle with their mathematics knowledge and skills developed in prior courses. Students need to be familiar with concepts from algebra including, but not limited to equations of lines, percentages, fractions, factoring, and solving word problems to be successful in accounting courses.

Spending a lot of time on mathematics review in an accounting class is not a desirable solution for possible information gaps or problems with recollection. The concept of just-in-time learning was initially borrowed from industry. In education, just-in-time learning suggests that learning is tailored to the individual student, provides easy access, and is directly related to the tasks at hand (see, for instance, Riel (1998) and Irvine (2015)). We have chosen to refer to the process we employed as a just-in-time review because it better describes the purpose of the project. The just-in-time review is a teaching technique used to provide materials to the students as they need them. In the case of an introductory accounting course, the students are provided with a quick assessment of mathematics outcomes needed for the course and resources that help them review materials where they need them.

The mathematics review for accounting students was one of several projects supported by the National Consortium for Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnership (SUMMIT-P) project at Saint Louis University. The goal of the just-in-time review project was to create resources for students that would help them review mathematics concepts and skills where necessary. The skills assessment that was developed, as well as the Google site that was set up to distribute the review materials, could easily be adapted by other institutions. The system is easy to use for both faculty and students. This paper will provide a brief overview of the project at Saint Louis University, the process used to foster collaborations between the mathematics and business faculty, and include a description of the development and implementation of the just-in-time mathematics review.

Mathematics and Business School Collaborations

> *"You said that we are looking at 43%, but you wrote down 0.43. How did you get that number? I don't understand how and why you went from 43% to 0.43."* – A student

The SUMMIT-P project at Saint Louis University is a collaboration between the Department of Mathematics and Statistics and the Chaifetz School of Business. Monthly meetings were held by a group known as the Mathematics-Business Committee during which the progress on individual projects taking place through SUMMIT-P was discussed. The meetings allowed mathematics and business faculty to interact and exchange ideas regularly.

A repeated theme in the discussions was the fact that some students in business had weaknesses in their mathematical backgrounds that the business faculty did not have time to address during class. Mathematics at the college algebra level is used extensively in accounting (McCarron & Burstein, 2017; Mkhize, 2019). However, students come into accounting classes with a broad range of mathematics backgrounds and abilities.

Some students have completed mathematics classes recently, while for other students there may be a significant gap in time between the last mathematics class completed and the current accounting class. Not remembering the fine details regarding mathematical notation and computations is a common and well-recognized phenomenon. It can be a real problem for the student who is expected to use the notation and be able to perform computations.

Spending time on mathematics review in a business class sub-optimizes the time available to focus on the primary course content, so ways to provide the necessary review and supporting materials that students could complete independently as needed were explored.

The faculty decided that a skills test and an opportunity for remediation at the beginning of the semester was the most effective way to address the issue. The accounting instructor did an inventory of mathematics topics that are used in the course. The mathematics topics were linked to the business concepts in the course to show students how the two are related and motivate the need for these mathematics skills in an accounting class.

To make a sustainable adjustment to a business course that would be implemented by multiple instructors, the Mathematics-Business Committee agreed that the intervention had to be done with minimal ongoing work from the business faculty and no fees for the students. The committee decided to use WeBWorK as the online platform to deliver the skills test (Bart & Pike, 2017). WeBWorK is a free, open source, homework system used by the Department of Mathematics and Statistics for other courses thereby increasing the likelihood of student familiarity with the tool. It has an extensive problem library that contained existing problems for the selected skills. The accounting professor selected the problems for the skills test from the problem library. The test is divided into five topics (see further detail below) so that students receive detailed feedback and can target their review only to relevant areas where a specific skills gap has been identified. To facilitate easy review for students, the mathematics faculty created a website using Google sites that allowed students to navigate to any of the five topics for which they need to refresh their understanding. Free online videos and problem sets from Khan Academy were selected by the accounting faculty, reviewed by the mathematics faculty, and then made available through the website.

The initial plan had been to provide the skills test and allow students to retake the test after reviewing the topics on which they needed a refresher. After a trial run, it was decided that having the test with feedback from the students and the website was sufficient for providing the just-in-time review. Retesting and documenting student progress was considered, but it increased the duration of the intervention to a point that sometimes exceeded the timing in the course where the mathematics skills were most applicable. In addition, it was agreed that the likelihood of long-term sustainability of the initiative is increased if it is a process that is as simple as possible, not intrusive to the students, and easy for faculty to administer.

Identifying Mathematical Topics used in Accounting

The topics for review were determined by the faculty teaching the accounting course. The topics are not intended to be challenging, but students often need to be reminded of how to perform fundamental computations. The skills test is truly meant as a review and not as an opportunity to teach students mathematics they may not have seen before.

Examples of how the five topics align with the accounting course content are provided on the website to help students understand why they are being asked to review these topics. Transfer of knowledge between courses is difficult for students and providing these explicit links between mathematics and accounting also helps students to understand why they need to review certain topics.

1. *Fractions and percentages* are used throughout the course and students need to have a solid grasp of these topics to follow the lectures. The review included multiplying and dividing fractions, and converting fractions to decimals. Some of the materials linked on

the website are short videos, while other links provide detailed written explanations. The resources have been chosen to provide a quick review.

2. *Factoring* is used in processes such as cost-volume-profit analysis, and the reviewed materials include both articles and videos explaining how one factors simple quadratics. The review includes factoring by grouping.
3. *Computational skills* including expressions with two variables are used extensively in all business applications. It is, in fact, quite common for business applications to have more than one variable. The review provides a quick overview and some examples.
4. *Graphing lines* are used in cost-volume-profit analysis. The review provided includes videos on how to find the slope given a graph and finding the slope given two points.
5. *Articulating word problems* is a concept necessary for cost-volume-profit analysis and incremental analysis. The review includes examples of percentages. The examples and practice problems were chosen because of their applications to business topics.

A skills test was devised in WeBWorK to assess these five topic areas. Aligning the skills to accounting concepts creates an efficient way to level-set the student. The test is scored so that students know how well they perform in each of the five areas. This helps optimize the additional review the students may need to do. They can still review all areas covered in the test but being able to focus first and foremost on the areas where they score lowest is most beneficial.

The website lists these five areas of mathematics content so that students can easily find the topics they need to review. The videos and pages have been chosen to provide a fast review of the subject matter. Creating a resource that is not too time intensive for the students increases the likelihood that they will make use of it. The topics covered and questions used in the skills test were selected by the accounting faculty. The selection of remediation material was a collaborative effort of mathematics and accounting faculty.

Implementation and Sustainability

The just-in-time review was piloted in Fall 2017. After the initial pilot, the involved faculty decided that the pre-and post-testing model was not optimal and moved to a model where students are now given the skills test early in the semester and are encouraged to engage with the review materials when necessary.

Students who took the skills test were able to review the mathematical concepts as needed. The online resources were chosen to facilitate a quick review. Short videos were selected so that each review would take no more than 15 minutes. Further resources were made available for students who want more practice. Students have commented in online discussions about the usefulness of the review.

The current format does not require significant work on the part of the accounting instructor and is easy to use by the students. Operational ease is needed to obtain the broad buy-in for the process to be used by multiple faculty across the sections of the course. Currently, the review is used in all sections of the accounting course it was designed for that are taught by full-time faculty. The total number of students involved is approximately 250 per academic year. The accounting faculty include an incentive for participation as part of the syllabus. Sample email verbiage is provided to all instructors to help explain the process to students. Good communication also helps create buy-in. One accounting faculty member provides enrollment information to a mathematics department colleague who sets up the WeBWorK assignment. A different accounting faculty member acts as the designated person for analyzing the skills test results that are collected early in the semester and also helps to coordinate the feedback provided to the students. The outreach to the students who need review is important. The students are meant to see the review as supportive and as an indication that faculty are caring and setting the students up for success. The result is students with stronger mathematics skills, which allows the accounting faculty to focus on the course subject matter.

Discussions are ongoing about the just-in-time review process as we are still using the skills test as a diagnostic at the beginning of the introductory accounting classes. This practice continued for all but one section after the pivot to teaching online during the pandemic. The current focus is on reviewing and updating the associated website to ensure that the review materials are easily accessible. Any website used in a course requires regular review and revisions to account for linked sites that are either no longer available or changes to web addresses after site updates. There are ongoing discussions about expanding this practice to other courses. In addition, the just-in-time review should be applicable to other disciplines.

Conclusion

The just-in-time review for accounting students has been successfully used at Saint Louis University for several years. The skills assessment using WeBWorK and the website created for the introductory accounting course can easily be duplicated for use by students and faculty at other institutions. Furthermore, the concept outlined in this paper can be applied to disciplines besides accounting. Creating an inventory of mathematical skills required for a course in a partner discipline and finding appropriate problems in the WeBWork library of online problems would take some time but is not a difficult process. Creating an online presence with links to online educational materials is similarly straightforward.

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Leveraging Interdisciplinary Expertise in Developing an Alternative Mathematics Pathway

Beverly Wood
Embry-Riddle Aeronautical University
Beverly.Wood@erau.edu

Debra T. Bourdeau
Embry-Riddle Aeronautical University
Debra.Taylor@erau.edu

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Abstract

How many instructors does it take for amazing course design? Or perhaps we should begin with "A mathematician, humanist, communication expert and statistician walk into a bar." This unlikely team has co-developed a pair of courses, Learning to Reason I: Art and Quotient and Learning to Reason II: Commerce and Flux, that deeply investigate quantitative reasoning from multiple perspectives. Blending elements of rhetoric, logic, and history with mathematical computation, representation, and application breaks through the perceived barriers between the unyielding, obstinate world of mathematics and the ambiguous, equivocal world of the humanities. Developing the courses as an interdisciplinary team of mathematicians and humanists has brought together multiple ways of reasoning and habits of mind that present students with experiences in critical thinking involving both numbers and words. These innovative courses investigate such diverse topics as the history of mathematics, ethics and statistics, mathematical art, logical fallacies, fun with spreadsheets, personal economics, communicating quantitatively, and even origami. These courses also provide an alternative mathematics pathway for students in our programs for which calculus is not required. This paper will examine this unique interdisciplinary course development experience that uses an asynchronous online modality to deliver content to students around the world.

Keywords

STEM, humanities

In recent years, it became evident that some students at STEM-focused universities face the same challenges in learning mathematics as adults returning to education later in life at institutions of all types. Jameson and Fusco (2014), for example, document lower levels of mathematics self-efficacy in adult learners while also noting that math anxiety is higher in non-traditional students. Compounding this issue, few degrees at Embry-Riddle Aeronautical University (ERAU) do not require one of the two versions of calculus (polynomial calculus and engineering calculus) that are offered. However, some degree programs allow for a choice between pre-calculus/polynomial calculus or college algebra/trigonometry for meeting the general education requirement of completing six credit hours of mathematics. These include non-STEM programs in Interdisciplinary Studies, Communication, Emergency Services, and Homeland Security. Given that there are several programs whose disciplines do not demand the skills represented in the Student Learning Outcomes (SLOs) for either of the existing options, there was clearly room for an alternative mathematics pathway for students in these non-STEM majors (Saxe & Braddy, 2015).

To accommodate these students, an initiative in the ERAU College of Arts and Sciences was created by two faculty who were working across different departments, Dr. Bourdeau (a humanist) and Dr. Wood (a mathematician), to include interdisciplinary perspectives in general education courses – Humanistic STEM (H-STEM). This initiative was underway when ERAU joined the NSF funded national consortium for Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnerships (SUMMIT-P) in the fall of 2019. While H-STEM focuses on crossing the boundaries of meta-disciplines to create multiple lenses of inquiry (Bourdeau & Wood, 2019), SUMMIT-P utilizes a robust collaborative process for mathematics faculty to work with faculty from client disciplines (physics, engineering, business, etc.) to improve knowledge transfer for students. These processes do not seem limited to only mathematical preparation for STEM fields but, rather, are useful in both STEM and non-STEM collaborations. Together, both projects stressed the need to eliminate disciplinary silos in a way that shows students the connections between their academic experiences and underscores the relevance of knowledge and skills from the classroom to the workplace.

Based on the history of success in STEM and STEM-adjacent (healthcare and business) collaborations through SUMMIT-P, faculty from the Humanities and Communication department and the STEM Education department worked together to create an alternative pair of mathematics courses that would meet the requirements of the ERAU general education Quantitative Reasoning competency without the rigid constraints of preparing students for calculus. The interdisciplinary team of content creators offered a variety of activities that demonstrate wide applicability of mathematical concepts in other disciplines as well as in common life experiences. The design collaboration is evident in materials developed to model the deep connections across disciplines and the meta-disciplines of STEM and humanities.

Listening to the Partner Discipline

After determining that an alternative pathway was needed, we chose to initially focus on one non-STEM degree, the Bachelor of Science in Communication. It was selected for its small size (approximately 36 students) and the fact that it is a shared program across two of the three ERAU campuses with an existing strong, collaborative relationship. The first step in developing a set of courses that would provide students with mathematics skills relevant to the communication discipline was to determine what those skills actually are. This was handled by providing communication subject-matter experts with the opportunity to explore and explain how mathematics impacts the discipline and what graduates need to know to be successful in the field.

To initiate the collaboration process, the fishbowl discussion technique (Hofrenning et al., 2020) was used. This technique involves an idea-sharing discussion of one group while a group of listeners observes, this protocol gave mathematics faculty the opportunity to listen to communication faculty from both campuses as they talked about the quantitative aspects of the careers for which their students are preparing. Fishbowl participants included mathematics faculty, who served mainly as observers but who could answer curriculum-specific questions as needed. A facilitator guided the discussion. Communication faculty responded to the facilitator's questions about how mathematics is used in the communication discipline. These predetermined questions are part of SUMMIT-P protocol (see https://www.summit-p.com/resources/collaboration-tools). Topics that emerged from this discussion included the importance of designing effective data visualization, the need for ethical reasoning in mathematics, and the application of problem-solving skills.

Based on that conversation, a list of learning outcomes was developed for two new courses, MATH 201 Learning to Reason I: Art and Quotient (see Table 1) and MATH 202 Learning to Reason II: Commerce and Flux (see Table 2). Some of the assignments such as preparing an annual budget for a human trafficking shelter or using design principles for presenting that budget fell clearly into disciplinary silos, while others were more collaborative by nature. For example, writing instructions to create origami using geometrical language.

Table 1

MATH 201 Student Learning Outcomes

1. Interpret verbal and visual media presentations of data.
2. Design effective data visualizations.
3. Apply proportional reasoning in multiple contexts.
4. Describe the ways that geometry appear in the natural world and art.
5. Distinguish between inductive and deductive reasoning.
6. Select appropriate technologies to compute, analyze and interpret information.
7. Recognize ethical dilemmas in dealing with quantitative information.
8. Identify the intellectual and cultural context in which mathematical progress has occurred.

Table 2

MATH 202 Student Learning Outcomes

1. Demonstrate financial literacy.
2. Critique multiple pathways to mathematical solutions.
3. Explain the logic of quantitative reasoning processes.
4. Manipulate mathematical functions in applied problem-solving.
5. Distinguish between inductive and deductive reasoning.
6. Select appropriate technologies to compute, analyze and interpret information.
7. Recognize ethical dilemmas in dealing with quantitative information.
8. Identify the intellectual and cultural context in which mathematical progress has occurred.

The Courses

Two three-hour courses were developed to meet the general education requirement of a six-hour math series. The course description, topics (see Table 3 and Table 4), and a sample activity for each course are described below.

MATH 201 – Learning to Reason: Art and Quotient

Title. The developers decided that a unique, eye-catching title that captured the interdisciplinary nature of these courses while relaying the focus areas of each was important. Specifically, proportionality, statistics, and probability, the areas of mathematics that emerged from the fishbowl discussion, are included. Additionally, a bit of trigonometry – supported by the Pythagorean Theorem – makes up the Quotient portion of the course. The Art portion includes origami, mathematical art exhibition, and exploration of the multiple meanings of the term "aspect ratio."

Catalog Description. The course addresses both the abstract and applied aspects of data science, proportionality, and geometric concepts. Exploration of the development of mathematics and the modern technologies used to apply ancient ideas to today's problems as well as the human need for creativity across disciplinary boundaries.

Table 3
Weekly Modules in MATH 201

Module 1	Where does math come from? History of mathematics / Timeline project
Module 2	Innocent until proven guilty: Logical fallacies / Proving the Pythagorean Theorem
Module 3	What are the chances? Monty Hall problem / Probability practice
Module 4	Do numbers lie? Professional ethics for statisticians / Data visualization
Module 5	A picture is worth a thousand words: Critique data visualizations / Association and correlation
Module 6	Five out of four people have trouble with fractions: Special ratios / Writing a press release with quantitative information and visuals
Module 7	The geometry of life: Origami / Perimeter, area, and volume
Module 8	The life of triangles: Ratios and proportions / Completing the timeline project
Module 9	Quantitative creativity: Find and describe art with mathematical language / Learning reflection

Assignment Example. Triangles of Life discussion (the penultimate module) requires students to make an audio/visual presentation of triangles they encounter in daily life or in vacation photos or from internet sites featuring places they would like to go. It should be noted that the initial offering of the course was in the fall of 2020 during the COVID-19 pandemic. Not only were they to find an image but also to explain whether it was included for aesthetics, structural integrity, or both, using appropriate mathematical language. For example, a "pentagonal pyramid roof" of a backyard birdhouse with edges of length "3.5" x 3" x 4"" which were used to determine that it was a scalene triangle. This assignment assessed not only the understanding of mathematical vocabulary but also the integration of symmetry and asymmetry into human environments, creating multiple lenses of inquiry. Students were required to make at least three discussion board posts about their findings. (For interested readers, the full syllabus can be found at www.humanisticstem.com.)

Grading. Student work is assessed via rubrics. The rubric's scoring guide includes points that apply to both disciplines (see Figure 1).

Figure 1

Rubric for Triangles of Life Assignment

MATH 201 Module 8 Converse Triangles of Life Rubric

You've already rated students with this rubric. Any major changes could affect their assessment results.

Criteria	Ratings			Pts
Timeliness Initial post is made no later than the end of the fourth day of the module.	10 pts On time	0 pts Not on time		10 pts
Finding Triangles Photo, video, or artwork of three triangles presented visually.	20 pts Three	10 pts Two	5 pts One	20 pts
Communicating mathematics Appropriate use of mathematical language to describe each of the chosen triangles and their beauty or utility.	30 pts Well done	20 pts Good work	10 pts Could be better	30 pts
Participation Responding to classmates' posts about your initial post and replies to at least two classmates' initial post with your remaining two triangle images/commentary.	30 pts Well done	20 pts Good work	10 pts Could be better	30 pts
Writing is professionally done, including current APA citations where needed.	10 pts Perfect	5 pts Readable	0 pts Poor	10 pts
				Total Points: 100

Student response. "I thought this was a really fun assignment," said the student who found an amazing number of triangles in their home décor. There was excellent engagement of all students, including finding additional triangles in their neighborhoods after seeing what other classmates found. Everyone in the class exceeded the required three posts in this discussion. The posts were unusually substantive.

MATH 202 – Learning to Reason: Commerce and Flux

Title. Additional topics that were suggested by communication faculty to be included in the course were experience with Excel, economic indicators, and understanding of mathematical vocabulary. A third of this course covers financial literacy with modules on the order of operations, functions, and basic calculus topics (using Desmos).

Catalog Description. A quantitative approach to life's decisions, addressing both the abstract and applied aspects of using mathematics in finance, technology, and design. Exploration of the development of mathematics and the technologies used to assist in decision-making.

Table 4
Weekly Modules in MATH 202

Module 1	Mathematical reasoning: *Mathematics for Human Flourishing* by Francis Su / Concept map of development of mathematical thinking
Module 2	Order of operations: Technical writing of instructions / Critique of student errors in sample exam
Module 3	Functions, relations and equations: Stepwise functions / Function families
Module 4	Fun with spreadsheets! Microsoft Excel training / Creating a budget for a human trafficking shelter
Module 5	Personal economics: Loans and credit / Present value, future value, and compound interest
Module 6	Economic indices: National economic indicators / Interest rate and amortization
Module 7	Communicating quantitatively: Critiquing economic articles / Presentation of economic concepts
Module 8	Quantifying change: Roller coaster calculus / Optimization
Module 9	Mathematicians are human: Mathematical disputes / Final concept map

Assignment Example. Following the module devoted to functions, and as an introduction to the financial unit, students are asked to create a budget for a human trafficking shelter under the assumption of a linear increase of clients over the course of the year. This project was inspired by the discussion with communication faculty that revolved around the skills that could be learned by using Microsoft's free, online Excel tutorials. The budget allows students to blend mathematics tasks with social concerns within the context of financial responsibility.

Student response. "Excel opens up so much and has an endless [number] of functions you can use it for." and "I'm really happy that you all decided to include Excel as a significant portion of this course. It will be SO valuable [in the future]."

The Faculty Experience

The faculty collaboration that produced MATH 201 and 202 was not without its challenges. One of the pitfalls of both team teaching and team development is the propensity for administrators to assume that each additional team member will certainly result in less work for everyone involved. The result is often less pay or divided course "credit" for team-developed or team-taught courses. Some institutions, not wanting to navigate the murkiness of the issues simply discourage (or even disallow) the practice. Some departments are reluctant to allocate precious and scarce faculty time when the resource will be shared with another unit.

Compounding these issues is the reality, of course, that team teaching and team development often involve the added elements of strategy meetings, division-of-labor discussions, conflict resolution, and additional editing complexities. Rather than lessening the workload, solid course development or teaching collaboration will increase the work required of all team members. Without administrative understanding or support, this fact can discourage classroom collaborations altogether or, at the very least, create a process steeped in frustration. Absolute buy-in from administrators is the first step in creating an atmosphere in which fruitful collaboration can occur.

When these obstacles are overcome, a team will then need to maneuver through other issues that can arise in interdisciplinary teams including varying expectations about writing quality, research methodology, assignment design, rubric deployment, and teaching philosophy. Discussions surrounding these concerns can be complex and seemingly unresolvable. Some of the questions that arise include: Should students compose lengthy written arguments? If so, who grades them? Should class sessions be focused on lectures or discussion? Is homework an essential element of the course? Are mechanics and style essential elements of written work? To what extent? These kinds of questions often led to the need for compromise in places where the disciplines had differing expectations. Navigating disciplinary diversity requires handling conflict in a way that moves the project forward.

The development of MATH 201 and MATH 202 included collaborators from four disciplines: mathematics, statistics, humanities, and communication. Each collaborator prepared mini-lecture recordings to be used in the courses. Some collaborators developed complete activities. Everyone engaged in the co-development of course assignments. Each person had different ideas about what concepts a course in their discipline should include, the types of assessments that were appropriate to ensure attainment of SLOs, and the appropriate workload for students. Additionally, while the courses would contain both humanities- and communication-focused elements, it was essential that there was sufficient mathematics content, to justify the MATH prefix and to ensure that students could use the courses to fulfill general education requirements in that area. The team had to agree to keep mathematics at the forefront while not diminishing the humanities and communication content which would have made those components seem less than fully integrated into the courses.

The humanist on the team, also a collaborator on the H-STEM project, determined that it was important that students see the connections between mathematics and arts/humanities. First, she wanted them to consider how mathematical elements were expressed in visual art. As a result, paintings by Crockett Johnson (1974) appear in each module of both courses. See Figure 2. Johnson's focus on mathematics and physics in his paintings makes him an ideal "guide" through the course, consistently reminding students that these worlds are not as distinct as they might imagine. These connections are reinforced in lessons throughout the course.

In the course, students are encouraged to create their own mathematical art through a work of origami. They are told that while they "will not be expected to construct a nonagon or a cubical parabola," they must create a set of instructions for their classmates to follow in their own attempts at paper folding.

Another module explores the connections between logic and mathematics by introducing students to both mathematical proof and logical fallacies. Not only do the students attempt to find real-world examples of fallacious arguments, but they also must select one of the 118 unique proofs of the Pythagorean Theorem to present in their own words. The rubric for this assignment reflects the humanities/mathematics blend, with an equal number of points awarded for communication of concepts and mathematical accuracy. These activities reflect the interdisciplinary nature of argumentation, reinforcing the value of these skills across their educational experience.

While it was easy enough to write these humanities-focused assignments from a disciplinary standpoint, the mathematicians on the team ensured that the team was tethered securely to the mathematical concepts in the course. Rather than simply "sprinkling in" the humanities, the selected assignments are fully integrated and pedagogically relevant. As discovered through the humanistic STEM discussions, this "blend" is the real strength of the collaboration.

Figure 2
Crocket Johnson (1974). Archimedes Transversal. Smithsonian National Museum of American History. Washington, DC.

Similarly, the communication faculty wanted to be sure that students could read, create and interpret data visualizations that would be needed in business contexts such as a press release or slide presentation. They also insisted that the courses include some discussion of ethics specific to data visualization and statistics. As a result, students created a moving average time series of economic data from the Bureau of Labor Statistics using Excel and writing about the line plot. The rubric for grading this assignment was evenly split between the quantitative accuracy and the communication of what the graphic reflects about the data. Using Edward Tufte's (2001) Principles of Graphical Excellence as discussed in his *The Visual Display of Quantitative Information*, students are asked to critique examples of effective and ineffective representations of data. Students use the Associated Press (2020) Stylebook to compose a press release using results from previous statistical assignments. The communication faculty also had an impact on the layout of the course; module landing pages were presented in an infographic style to illustrate visual communication.

While maintaining the humanities and communication content that was so important to those members of the team, the mathematician faculty worked to ensure that the courses connect these disciplines effectively to mathematics and at a sufficient level of quantitative competency to be a course worthy of the MATH prefix. During the fishbowl activity with Communication and Humanities faculty, the mathematics faculty listened as the faculty shared topics in their disciplines related to quantitative reasoning and statistical literacy. These specific topics are included in the first four SLOs for each of the courses (Tables 1 and 2). The remaining four SLOs are identical in both courses and blend the elements where the seemingly disparate disciplines have overlap and usefully inform one another. The mathematician's role was to ensure that the blended elements balanced the concerns of all four disciplines without obscuring the quantitative objectives of a mathematics course.

Achieving multi-level buy-in for such a complex course development project is another challenge that required a team effort. At ERAU, the Instructional Design and Development (IDD) department had to be persuaded that the expertise of *four* faculty developers (instead of the typical one or two) added value to the project. It was an admittedly unusual request for a process that typically pairs one faculty subject-matter expert with one instructional designer. Designating one point of contact for communication with IDD assuaged some of the concerns. Typically, the instructional designer's meetings were held specifically with the individual serving as the point of contact, with only occasional full-team meetings at integral points in the development process. This eliminated the possibility of multiple, even competing, points of view being expressed in design and development meetings. The point of contact obtained the consensus of the team before representing the group in design meetings.

Anticipating concerns about faculty credentials for such an interdisciplinary course, the development team worked to ensure that the course (prefixed as a mathematics course) did not require specialized knowledge in humanities or communication that would prevent a mathematician from having mastery of the course material. Additionally, the humanities and communication faculty team members developed extensive background pieces to fully contextualize each activity. Finally, thorough explanations were added to the "Information for Instructors" area of the asynchronous course. Because ERAU uses a course template model for course development, these resources are available to instructors who were not part of the development team.

Student Responses

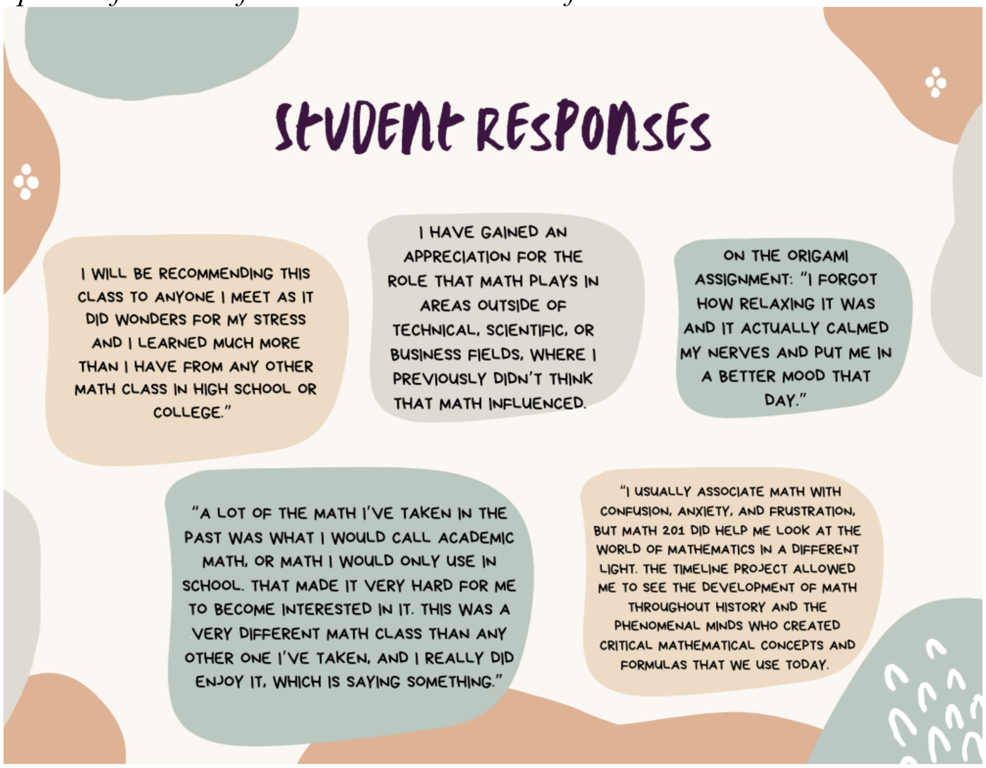
While the courses are too new to provide longitudinal data, students have been responding favorably to the educational experience as evidenced by their end-of-course evaluations. Responses have focused on the practical application of the skills reinforced in the courses as well as how the classes were able to alleviate math anxiety. A selection of student responses appears below (see Figure 3).

Sustaining the Project

This project shows significant potential for long-term sustainability. The STEM Education department publicized the course to increase interest among potential instructors. Because most courses are staffed by adjunct faculty, it is essential to create clear lines of communication about new initiatives. A list of faculty interested in teaching the courses was compiled. In Fall 2021, MATH 201 was taught by a faculty member who did not serve on the development team. Dr. Wood worked closely with the adjunct instructor to ensure that the course delivery aligned with the philosophy of the course development team. After teaching MATH 201, this instructor commented to the team, "Thank you for creating such a wonderful class!!! I very much enjoyed teaching MATH 201 and am looking forward to MATH202."

Figure 3

Student Responses from a Reflection Task at the End of MATH 201 and MATH 202



Since their initial offerings, there have been conversations with advisors and the program chairs about adding the courses as options for three additional degrees. Because of the MATH prefix, the courses belong to the STEM Education department with the mathematician on this project as the nominal course monitor. The collaborative development, however, leads to further teamwork when questions of content or pedagogy arise. College policy dictates regular redevelopment of online templates which will be opportunities to bring the developers back together. This will be in addition to the informal conversations about student interest and performance in the courses as well as reviewing the end-of-course student surveys. New faculty are being recruited to teach an additional section of each in the upcoming academic year.

Importantly, the individuals involved in College's H-STEM initiative are highly supportive of these two mathematics courses and are actively looking for additional course collaborations between the STEM faculty and faculty in other departments. For example, Baseball History and Statistics is a course currently under development as a collaboration between mathematics and history. Next is the redevelopment of a course, Digital Humanities and History of Communication Technology, that will feature collaborative reviews to integrate the STEM perspective more deeply into the curriculum of the Humanities and Communication departments.

Finally, the team has an active dissemination schedule, including presentations at conferences in multiple disciplines, from the National Numeracy Network to the Northeast Modern Language Association. Providing a model for successful interdisciplinary course development, the team has additional contributions planned for both the multi-institutional SUMMIT-P project as well as the ERAU H-STEM initiative.

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STATISTICS FOR NURSING AND ALLIED HEALTH AT SAINT LOUIS UNIVERSITY IN THE SPIRIT OF SUMMIT-P

Kimberly S. Druschel
Saint Louis University
kimberly.druschel@slu.edu

Michael May
Saint Louis University
mike.may@slu.edu

Elizabeth Gockel Blessing
Saint Louis University
elizabeth.gockelblessing@health.slu.edu

https://doi.org/10.25891/n8k4-qy03

ABSTRACT

This paper describes the renewal of a consumer-based elementary statistics course to benefit students in the nursing and allied health disciplines. While the goal of the course transformation was initially to update the pedagogy of the course and ensure students are able to make connections between the course material and their majors, that goal expanded to include the needs and objectives of the client disciplines. This expanded goal was accomplished by incorporating insights gained from a SUMMIT-P business school collaboration and was based on the Curriculum Foundations project recommendations. The paper addresses course projects, instructor development, faculty roles, and interactions with stakeholders. The influence of SUMMIT-P on the course renewal as well as sustainability plans are also shared.

KEYWORDS

consumer-based statistics, statistics for healthcare, course development

This paper describes the process of renewing a statistics course for nursing and allied health, STAT 1100, at Saint Louis University. The interactions between mathematics and client discipline faculty throughout this process were intentionally modeled after those Father May employed when reforming a business school course for a different project as part of a National Consortium for Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnership (SUMMIT-P). In both cases, the course renewal project started with an attempt by mathematics faculty to improve their teaching by implementing reforms recommended by professional organizations. The goal was to develop a sustainable unit of change and institutionalize the reform across all sections of a multi-section course. In the case of the statistics course, motivations for reform also were based on client discipline concerns about student knowledge retention, instructors' discontent with the lack of substance in the course, and an interest in developing a generic, project-driven, quantitative reasoning/statistics course.

With both courses, a faculty member implemented reform in a pilot section and then established a dialogue about the course with the associate deans of the colleges housing the client disciplines. When the associate deans affirmed that the course changes aligned with the course goals in the client disciplines, faculty representatives from them were brought in to collaborate and help further refine the course. The collaboration between mathematics and client disciplines was formalized with the formation of structured meetings with stakeholders. The use of this model, developed through the SUMMIT-P partnership, has helped ensure that the efforts are sustainable and stable.

The discussions regarding STAT 1100 led to initiating larger structural changes in how introductory statistics courses are structured and maintained by the mathematics department. In particular, we started having once-a-semester meetings with stakeholders of introductory statistics courses, to ensure the courses offered align with the partner discipline needs. In the short term, the renewal process is being applied to a second introductory statistics course, with a higher mathematics prerequisite, which provides an in-depth study of theory and computations, and includes analyzing large data sets using the statistics software package R. In the medium-term we are planning to apply the renewal process to create a different version of the introductory consumer-based statistics course, working with a different set of partner disciplines.

The Scenario at Saint Louis University: Department Climate and Course Renewal

The Department of Mathematics and Statistics (referred to in this paper as the department) is a Ph.D. granting department whose faculty members have interests in course development, project-driven or flipped courses, and client discipline outreach activities. The department is supportive of pedagogical development, with clusters of faculty members working together on courses.

For service courses, the department tends to teach multiple sections of each course, each of which is capped at 30-35 students. These courses are often taught by adjuncts or graduate students, with the percentage of courses taught by full-time faculty diminishing in recent years. Unfortunately, the service courses for disciplines that are not mathematics intensive are often a low priority for both the department and the partner disciplines.

On a bigger scale, the university has been making strides in the past few years in breaking down discipline, department, and college silos, including those relevant to the delivery, and content of non-major courses by several initiatives including: (1) brown bag lunches about STEM teaching, (2) stakeholders meetings for course clusters, and (3) a new set of core requirements for all undergraduates based on the necessary conversations to make these kinds of changes.

An Overview of a Typical Course Renovation Process

The course renewal process almost always starts with a single faculty member looking at the course and saying "we can do better" in course delivery. The individual's work involves making a particular improvement as well as the effort to utilize the wisdom of the profession when deciding what "better" means. If the changes to the course are to be sustainable, the effort will have to broaden beyond a single faculty member's inspiration in order to become department policy. For courses geared toward students in partner disciplines, the faculty representatives from these disciplines also need to be involved so that the students are getting the same message from both the mathematics instructors and the partner discipline faculty. Ideally, consultations are structured to ensure the sustainability and growth of the course renovation. This renovation process can be thought of in four intertwined stages. The stages listed below are written specifically for our undertaking:

- Recognize that we can do better with the course we are teaching.
- To effectively teach a service course, secure the support of the students' home departments. We need to move the discussion from which courses students should take to the student learning objectives and how those objectives fit into the curriculum.
- Teaching a better course generally means asking the students to work harder, or at least to work in a manner that is different from the way they are accustomed. To make the worthwhile change, we need to consistently employ better pedagogical practices across all sections of the course. We also need to align our suggested changes with the recommendations of professional organizations, so we can explain why we are asking the students to make adjustments to their learning practices.
- Establish structures that will sustain the effort and the cooperation between mathematics and partner discipline faculty.

The Course Renovation Process for the Consumer-Based Statistics Course

The renewal of the consumer-based statistics course, STAT 1100, was informed by earlier pedagogical projects in the department, including May et al. (2020), a SUMMIT-P business school and mathematics collaboration. The recommendations described in the *Curriculum Foundations Project: Voices of the Partner Disciplines* (Ganter & Barker, 2004) developed by the Curriculum Renewal Across the First Two Years (CRAFTY) committee of the Mathematical Association of America, the *CUPM Curriculum Guide 2004* developed by the Committee on the Undergraduate Program in Mathematics [CUPM], and the *Guidelines for Assessment and Instruction in Statistics* ([GAISE], 2016) were highlighted during the initial discussions. Once the general structure of the course was in place, it was time to consult with partner disciplines about incorporating discipline-specific applications into the course.

A Culture that Provided Readiness for Course Renovation

CRAFTY recommends (Ganter & Barker, 2004) that mathematics courses should emphasize (1) conceptual understanding, (2) problem solving skills, (3) mathematical modeling,

(4) communication skills, and (5) provide a balance between perspectives. These are five principles that many faculty within the department believe are valuable for courses at all levels. These recommendations were explicitly discussed when the department debated the available choices of reform calculus textbooks over two decades ago. The result was that the department chose textbooks embracing these CRAFTY principles. These areas of emphasis are still brought up during the department "Calculunches". Several members of the department were involved in a SUMMIT-P project, which explicitly uses CRAFTY principles outlined in Ganter and Barker (2004) and MAA (2004). However, outside of the SUMMIT-P work, the CRAFTY principles were mainly considered when deciding how to make mathematics classes more effective for business students. The work on that project (May et al., 2020) was the basis for discussions about models for collaborating with other disciplines and about building structures to support the sustainability of pedagogical reform.

The lead innovator on the statistics project, K. Druschel, worked on the creation of STAT 1100 over 10 years ago. Her ideas for the course grew out of her experience with including projects in calculus, statistics, and computer science courses in which students were encouraged to share examples that were of interest to them. As the Director of Computer Science in the Department of Mathematics and Computer Science, she developed the Scientific Programming course, which included projects, in response to input from the client disciplines in the College of Engineering. When she revisited the STAT 1100 course after several years of teaching other courses, she realized that her impetus to include projects, as well as some healthcare applications, had dwindled. She took on the task of making the course better and of doing it in a way that would make the changes sustainable.

The Application of CRAFTY Principles

Druschel's work was initially informed by the CRAFTY and GAISE principles by happenstance. Rather than starting by reading the CRAFTY reports (CUPM, 2004; Ganter and Barker, 2004), she applied lessons she had learned by teaching a variety of courses that had been refined based on discussions with like-minded members of the department. Of the five CRAFTY principles listed above those that most strongly informed the changes to STAT 1100, a consumer-based statistics class, are conceptual understanding, communication skills, and a balance between perspectives. The primary components included in the updated course are the use of a semi-flipped class model for more active learning and the inclusion of group projects. Projects for this course require students to interpret the statistics in context, to submit an organized presentation, and to write clearly. These requirements are reinforced by the specific provisions for these elements in the grading rubric for the projects. In these projects, students analyze Medicare Hospital Care Compare data (Center for Medicare and Medicaid Services, 2022) using a variety of descriptive and inferential statistics tools. Students also consider how statistics is useful to their field. In this way, the balance between perspectives is incorporated into the group projects.

The CRAFTY recommendations (Ganter & Barker, 2004) include priorities for content, topics, and courses. The recommendation of most value to STAT 1100 is that statistics be offered during the first two years of the college experience and that the material covered in the course be motivated by a variety of examples and real data sets, including data collected by students. This recommendation is similar to the recommendation found in the GAISE standards stating that courses should "integrate real data with a context and a purpose" (GAISE, 2016).

Students take a deep dive into the Medicare Hospital Care Compare website and dataset (Center for Medicare and Medicaid Services [CMS], 2022) and the Medicare Mapping Healthcare Disparities website (CMS Office of Minority Health, 2022). Students also report on the use of statistics in articles that they read in their fields.

CRAFTY also has recommendations (Ganter & Barker, 2004) on the uses of instructional techniques and technology in courses. There have been regular departmental conversations about the use of different teaching methods and technology and the inclusion of projects since the days of calculus and differential equations course reforms. A variety of technologies have been used in calculus and business calculus. In conversations concerning the two introductory statistics courses, client disciplines have clearly delineated those majors which require a consumer-based course with minimal use of technology and those majors which require a different course using the statistical software R.

Additionally, CRAFTY (Ganter & Barker, 2004) recommendations encourage improvements to interdisciplinary cooperation. This can be unwieldy at times, as improving interdisciplinary cooperation needs to take place at a departmental level and requires time and negotiation. Efforts to improve interdisciplinary partnerships in a course are most fruitful when the mathematics department does not start with a clean slate but instead begins by determining what the client disciplines want the course to accomplish and then work to make adjustments and specifications. Such was the case with the SUMMIT-P business school and mathematics collaboration (May et al., 2020) as well as with the collaboration between statistics, health sciences, and other client disciplines for the renewal of STAT 1100. In particular, the supportive efforts of Associate Dean Gockel-Blessing in the Doisy College of Health Sciences and Associate Dean Laurie Russell in the College of Arts and Sciences propelled this interdisciplinary partnership forward.

In stakeholder meetings with client disciplines, Druschel and May presented the course format and the required projects. They indicated that projects are a sizeable portion of the course grade. They also noted that exams have less weight than what is typical for a standard statistics course and that the exams are not multiple choice. Stakeholders were very happy with the full course package, including the planned assessment measures. Thus, without addressing the recommendation explicitly, the CRAFTY (Ganter and Barker, 2004) call to "emphasize the use of appropriate assessment" is part of the course structure.

In Fall 2017, as Druschel piloted the updated STAT 1100 course, she participated in a university-sponsored trip to an American Association of Colleges and Universities STEM education conference. While she was aware of the CRAFTY recommendations (CUPM, 2004; Ganter & Barker, 2004) and May et al. (2020) SUMMIT-P work, the first time she focused explicitly on the CRAFTY recommendations was during a CRAFTY workshop at the conference on the fishbowl practice to listen to and understand client disciplines' needs. This workshop also piqued the interests of other faculty representatives from other disciplines on campus which resulted in conversations about potential future collaborations for calculus reform.

After the conference, several members of the faculty group attending the conference organized the university's first brown bag discussion on STEM education. Druschel also initiated departmental seminars on innovation in mathematics education which paved the way for other STEM-focused brown bag discussions. During the mathematics teaching seminar, Druschel met a graduate student, K. Radler, and learned of her strong interest in reform education. These connections led to the development of projects for STAT 1100. The CRAFTY workshop also reminded Druschel of the value of outreach to client disciplines which led to working with May in Spring 2018 to revisit the client discipline discussions on STAT 1100. This, in turn, led to cross-discipline collaborations to work on course development for a renewed version of STAT 1100 and the implementation of a multi-section pilot of the course.

Historical Perspective of STAT 1100

STAT 1100 is taught in sections of 35 students with about ten sections offered per year. While there had been some full-time faculty involvement when the course first came into existence, because of cutbacks, the course was primarily taught by adjunct instructors and graduate teaching assistants with little oversight. Students paid little attention to standard PowerPoint lectures and multiple-choice exams were given which resulted in minimal retention of the course content. In fact, a statistics knowledge quiz given to students in a follow-up nursing course indicated that students retained little of what they learned in STAT 1100. This correlated with anecdotal observations shared by instructors in follow-up courses.

Development Stages of a Multi-Section Consumer-Based Statistics Course for Healthcare Majors

Stage One – An Internal Pedagogical Project

In Fall 2017, in response to concerns from instructors as well as the department chair that the course lacked sufficient content and students were not engaged in the course, in addition to concerns by some client disciplines about knowledge retention, Druschel piloted a STAT 1100 course that featured group projects. To address these concerns, one natural solution was to add more opportunities for discipline-focused interpretations of statistics. So, in the pilot course, students found discipline-related (mostly healthcare) articles containing examples of the statistical concepts covered in class and subsequently answered a series of questions about them. The instructor provided short lectures on the course material, followed by the students completing worksheets in small groups. It was a lively course and students did well on the projects, as well as on exams. They indicated on an end-of-course survey that they were satisfied with the learning experience. In response to a survey question about whether they learned more as a result of completing in-class work, 10 strongly agreed, 15 agreed, 1 had no opinion, 5 disagreed, and 1 strongly disagreed. For a question about in-class work fitting their learning style, the distribution was 11, 14, 3, 2, 2, respectively. And for a question about in-class work preparing them for other courses or their career the distribution was 4, 14, 7, 7, 0, respectively.

Stage Two – Starting Negotiations with Client Disciplines

In Spring 2018, Druschel and May consulted with faculty in nursing and other non-pre-med health sciences about their students' statistics course needs. They shared information from the pilot course, including the projects and student satisfaction and assessment data. By using the cross-discipline collaboration listening techniques advocated by CRAFTY and successfully implemented in the May et al. (2020) business school SUMMIT-P project, they learned about the content of courses in the disciplines with a statistics course prerequisite and about how students use statistics in their senior projects. The client discipline faculty confirmed that the students should be able to read and apply statistical studies, and rarely need to work with large datasets, which is a requirement of another introductory statistics course. Representatives from the client disciplines shared sources for articles and datasets that would be relevant to the students and discussed collecting statistics knowledge retention assessment data in follow up courses. The client disciplines suggested the use of Hospital Compare data (Center for Medicare and Medicaid Services, 2022a & 2022b) for students in these disciplines who will take STAT 1100. The faculty representatives from the client disciplines were enthusiastic about the form, content, and outcome of the pilot course and asked that the course be implemented in the same format across course sections. The next question was whether the pilot could be implemented across all STAT 1100 sections and how instructors could be encouraged to participate.

Stage Three – Institutionalizing the Reforms, Involving Other Instructors

A larger pilot for Fall 2018 was implemented. In Summer 2018, Druschel and Radler created a template and a syllabus for a multi-section STAT 1100 course. The template included the routine online homework and a set of 10 projects based on some modifications to the projects used in the pilot course. For example, some projects were changed from "find an article in your discipline and answer these questions about the statistics in the article" to "make a brief poll and collect and appropriately analyze the collected data."

The syllabus outlined that the course format would follow a partially flipped classroom format. Exams counted for less than a third of the final course grade. Exams were not coordinated across sections, but sample exams were shared. The exams consist of short response questions with a few open-ended questions.

The Center for Teaching and Transformative Learning (CTTL) was consulted about engaging other instructors to teach a partially flipped course with group projects. Two instructors for three courses agreed to teach the course using the projects. They took part in training on using the prepared and shared materials. A website with teaching resources was also provided.

Survey data indicated students who completed the revised version of STAT 1100 did not feel the partially flipped instruction model and the projects fit their learning style or added interest to the class, or helped prepare them for further courses. For example, on a scale from 1 (strongly agree) to 5 (strongly disagree), for a question about learning style the mean for each instructor was 3.52 and 3.56, respectively. The average responses for a question on being prepared for future courses were 3.48 and 3.78, respectively. For a question about in-class work making the class more interesting, the mean responses were 3.10 and 3.04, respectively. Lastly, for a question on satisfaction with the learning experience, the mean responses were 3.71 and 1.93, respectively.

We realized through analysis of the assessment data and survey comments, and from conversations with instructors, that part of the students' dissatisfaction was due to the fact that the new version of the course required students to develop a deeper understanding of the content which, in turn, required more work on the part of the students. However, the data also indicated that there was a need to have more uniformity across all the sections of the course and better communication with students about the reasons for the course structure.

Stage Four – Institutionalizing the Reforms, Standardizing Sections

By Spring 2019 all sections of STAT 1100 were being taught in a partially flipped model format with group projects. Instructors were assigned to sections of the course based on their willingness to teach the course in this format. Instructors were given training in best practices for this instructional method. They also participated in regular instructor meetings throughout the semester. The projects were revised to remove the burden of finding articles from the students. However, students were still required to search for examples of real-world data and the use of statistics in their field. We elaborate on how we engaged students in exploring data and the related statistics in the projects section below. Pre-and post-course student surveys were conducted. Results indicated an increase in student confidence in their numerical skills with 63% agreeing or strongly agreeing that their confidence had increased. There was also an increase in the belief that statistics is relevant to their field.

Stage Five – Institutionalizing the Reforms, Training Instructors

Using feedback from instructors who taught the course in Fall 2019, Druschel and Radler engaged another graduate student, S. Salihovic, and an adjunct instructor, L. Miller, in a revision of the projects. During this time, instructor meetings and training continued. These efforts helped build a community of instructors with more enthusiasm for teaching the course. Graduate student and adjunct instructor involvement in the development of a course is not a standard practice in the department, but certainly seemed beneficial.

In addition, a presentation outlining the course renovation was made by May, Druschel, and Radler to Associate Dean Gockel-Blessing on the feedback from the course and resulting adjustments to the projects and other course components. In a similar fashion to what took place during the earlier SUMMIT-P work with partners in business (May et al., 2020), this led Dean Gockel-Blessing to schedule stakeholders' meetings about the revised course.

Stage Six – Dealing with Disruptions due to the COVID-19 Pandemic

In Spring 2020, as COVID necessitated that courses be taught online, the structure of the projects allowed for their use in an online format. It should be noted that the article reports and projects account for about a third of the course grade, which puts less emphasis on exams. This worked well for the online format. The main modifications that were made to the course included the development of mini-lecture videos and adjustments to exams that could not be proctored in person. Many instructors opted to allow extended completion times for exam and include more essay style questions. Projects were completed in small groups using Zoom breakout sessions. Additionally, the issues with academic dishonesty from cheating on exams was significantly ameliorated, due to the fact that a sizeable portion of the grade was based on students working on projects in small groups as well as reporting on discipline-specific articles and data they found.

Stage Seven – Adapting to Online Education

In summer 2020, Druschel taught a totally asynchronous version of course using the projects. She added more examples of hospital comparison data to the mini-lecture videos and developed a Blackboard template for the course. She also incorporated more data from Hospital Compare data or other healthcare measures into exam questions and developed an R template for generating multiple versions of exams. These materials were adopted by some instructors who taught the course in an asynchronous format in Fall 2020, Spring 2021, and Summer 2021. The exams became part of the library of exams that is shared by instructors.

Stage Eight – Peer Review and Involving Senior Faculty

In-person classes resumed in Fall 2021. Two sections of the course were taught by the department chair, Dr. Clair, and another section was taught by a graduate student, M. Silverglate. Both instructors have extensive statistics backgrounds and teaching experience, but they had not taught a consumer-based statistics course before that semester. All materials and projects from previous course offerings were shared with them. Clair made some improvements to the projects.

Their feedback in casual conversations as well as during scheduled meetings provided additional information for course modifications and also provided evidence that the course structure is amenable to both students and faculty. They also suggested further changes for the projects and the development of a more robust bank of articles for students to use for the article reports. Additionally, Druschel observed Silverglate's class and noted her extensive use of interactive Desmos slides in the lecture portion of class prior to the student work on the projects. As a result, Silverglate developed additional Desmos slides using the heath care data. These slides were used in Spring 2022 by some instructors.

Stage Nine – A New Sustainable Normal

The cadre of instructors for Spring 2022 included four instructors who have previously taught the course as well as one new graduate student and one new adjunct instructor. Course materials including PowerPoint slides, videos, exams, Desmos slides (updated by Silverglate), projects, an online homework template, and a website with active learning resources were shared with the instructors. During a pre-semester meeting, the partially flipped class model was shared with the instructors along with the rationale behind and logistics for using the projects. Veteran teachers shared their experiences with the faculty who were teaching the course for the first time. Throughout the semester additional instructor meetings took place to provide further support to the instructional team. The feedback from the instructors throughout the semester was positive. However, some instructors had difficulties fitting in all projects and opted to exclude some portions of the projects. This is an issue that will be addressed in further iterations of the course.

Article Reports and Projects

STAT 1100 has two basic types of group projects: (1) article reports that students complete outside of class and (2) in-class projects. Projects are geared towards the students' interests and their areas of study, which, in this case, are predominantly in healthcare fields. Of great benefit is the fact that the course structure, which combines finding articles with statistics related to majors and projects exploring substantial and relevant real-world datasets as consumers of statistics, are transferrable to other clusters of majors.

Article Reports

Students complete two article report projects, one in the first half of the course and the other in the second half of the course. Students are given an extensive and diverse list of articles to choose from. Resources to find their own articles if they so choose were also provided to the students. Students have the option to earn extra credit for doing so. The first article report covers study design, graphical representations of data, descriptive statistics, and the normal distribution. It may take a combination of two to three articles to cover all the topics. The second project addresses probability, regression, and inference. Students' reports are generally well-written, including cogent summaries of the articles and fairly accurate reports on the relevant statistics. The article analysis serves as a preview for what students can expect in subsequent courses which have STAT 1100 as a prerequisite. Examples include evidence based nursing or clinical research and design in physical therapy.

Vignette – Lee University

I use a similar assignment in my class Introduction to Research Methods and Statistics, a sophomore-level course for students majoring in psychology, at Lee University. In my version of the assignment, students must find empirical journal articles that address a topic of their choice. Students then select a few questions to answer from a list of provided questions, all of which are designed to help students identify the major components of a journal article (e.g., What are the researchers' hypotheses? What were the key results from the study? What are the strengths/limitations of this research?). In addition, students complete this assignment twice during the semester. When writing their second paper, students answer the same questions about a different empirical article, in addition they must also attend more carefully to APA style formatting requirements. Anecdotally, students have reported that this assignment is a useful introduction to finding and summarizing journal articles, and a helpful springboard for the literature review assignment they complete later in the semester. – Bryan Poole, Associate Professor of Psychology, Department of Behavioral & Social Sciences

In-Class Projects

There is generally one in-class project for every one or two chapters of course material. The projects occur during the second half of the class period and are designed to reinforce material covered during the first half of the class period. The course begins with a mini-project which asks students to imagine how statistics might be used in their fields or areas of interest and to provide examples of discipline-focused observational studies and experiments. Besides providing a motivational on-ramp for students, this project is intended to introduce students to working in Google docs and turning in a group project.

The activities in the remaining projects are mostly centered on data related to the Hospital Compare website (CMS, 2022b), a website maintained by Medicare that allows healthcare consumers to compare many typical aspects of patient care such as costs, readmission rates, wait time for emergency care, and patients' ratings of their experience at hospitals. The use of this dataset was specifically recommended by partner discipline faculty. The goal in these project activities is to have students look deeply at a substantial and extremely relevant scenario that involves a coherent dataset, explore the data, and view the scenario both as consumers and as makers of the hospital data and statistics. By tailoring the projects from the public website's information and the provided background data, the instructor may determine the balance between consumer-based analysis and data manipulation for the statistics course.

The questions included in the projects are of two types. Students find data on the website for their choice of hospitals and answer statistics questions about that data or use the data to complete basic calculations. The students are then asked to interpret the results within the healthcare or community context or make conjectures about the results. There are also activities which rely on graphs, tables, or statistics created by Druschel from datasets on over 4,000 hospitals from CMS (2022a) which provides the data for the Hospital Compare website. On the website one can only compare data from three hospitals at a time and students select hospitals that are familiar to them or hospitals in a select region.

Other activities include making conjectures about and reporting on how various statistical concepts are used in their own fields, finding and describing graphs about the COVID-19 pandemic, and analyzing information and graphs from the extensive Medicare Healthcare Disparities website (CMS Office of Minority Health, 2022).

Project Activities

This section briefly describes highlights of activities for seven course projects. These descriptions are not exhaustive in nature, as the projects are extensive and illustrate almost every topic covered in the textbook. These projects are located on the project website (Clair, et al. 2022).

The first project is designed for students to explore the basic vocabulary in statistics: variables, data types, populations, bias, percentages, and statistical studies. Students list variables in their field for each of the given types, such as numerical and discrete. Students are introduced to the Hospital Compare website (CMS, 2022b) by choosing three hospitals from the website (searchable via location) and reporting on data for each of them. They describe the data type (such as qualitative and ordinal), discuss the types of error that might occur and determine whether the variable should be labeled as explanatory or response. They then compare several hospital variables values to practice working with percentages.

A further activity introduces the basic notion of confidence interval and statistical significance. Students complete a quick calculation with the hospital data. For example, they might use a confidence interval for infection rates. They then provide an explanation about how the value compares to the national or state average.

The second project allows students to explore graphs, basic descriptive statistics, and false positive values. The first task in this project is to find three different types of graphs for COVID-19 data, and then identify the components and the information conveyed in two of the graphs. Another question asks students to determine how false positive or negative values might occur for an example in their field. They use a website to calculate the percentage of false positives and false negatives and determine the accuracy for their example according to prevalence, sensitivity, and specificity. Students next analyze histograms and box plots created from Hospital Compare data (CMS, 2022b) and compare the values for their hospitals to the graphs. They consider, for example, the quartiles that the values fall in and the percentage of hospitals that are comparatively better than one of their hospitals. Students explore the value of side-by-side boxplots, providing, for example, boxplots of southern states hospital emergency room wait times and making conjectures about the reasons for similarities and differences. To assess individual learning and contribution, all projects have an individual portion which includes a question about the contribution of each person to the group portion of the project. For this project, the individual portion also requires students to report on graphs found in Medicare's Healthcare Disparity website (CMS Office of Minority Health, 2022).

For the third project, students analyze three histograms and fitted normal curves, as well as descriptive statistics, for hospitals' readmission rates and patient approval ratings. Students identify the 68%-95%-99.7% locations or related proportions in the normal distributions or determine the probability that an arbitrary hospital does better than one of their chosen hospitals according to one of these measures.

Project four is a light introduction to probability with problems about: (1) the statistical significance of various hospital measures, (2) expected cost of an ER visit, (3) a Venn diagram that includes different measures of ER wait times and (4) probability statements about the categories of nurse communication effectiveness from data from Hospital Compare (CMS, 2022b).

The fifth project addresses scatter plots and linear regression. It includes a scatter plot of two measures of ER wait times for hospitals in Montana. Students identify a few outliers in the plot, find the towns for those outliers from a given list, and make conjectures about why they are outliers. Another task consists of deciding whether a given hospital is above the value predicted by the regression line. Students match correlation coefficients with four different scatter plots for various measures for California hospitals, discuss the strength of the correlation for a given pair of variables and the reasons for the occurrence. They then search for data for one California hospital and analyze how the hospital fits within the various scatter plots. They determine which hospital they would prefer to go to based on information provided in a scatter plot and provide statistical reasons for their selection.

The sixth project highlights the sampling distribution, confidence intervals and hypothesis testing. Students mimic a random sample by searching for data on the average payment for hip/knee replacement for various hospitals, then compute the sample average and compare it to the true population average and evaluate the difference between the two values. Students are given a graph of a sampling distribution for this measure. Students then compare the distribution to the histogram for the entire population of hospitals. Other questions include calculating a confidence interval for the proportion of patients who reported their nurses always communicate well and testing a hypothesis about the average payment for heart attack patient care at a given hospital.

Project seven covers hypothesis testing for proportions, the t test, the Chi-square test and ANOVA. Students apply a Chi-square test to data for Missouri hospitals to determine whether patient ratings of hospital cleanliness and patient ratings of hospital quietness are independent. They also calculate a confidence interval for the average payment for pneumonia patient visits. Students use an ANOVA test to determine whether there is evidence that the mean average wait times at hospital emergency rooms varies for four different states. Hypothesis testing is also employed to analyze whether the rate at which severe sepsis is treated properly at a given hospital is better than the 2019 national average.

Instructor Development

The professional development provided to graduate students and adjunct instructors teaching courses in the department include a meeting at the beginning of the academic year and mandatory mid-semester classroom observations. Feedback is provided to both the instructor and the supervisor of introductory courses. The Center for Transformational Teaching and Learning (CTTL) offers a certificate in University Teaching Skills. Graduate students often participate and, as part of the program, are mentored by a department faculty member.

In the past decade, most mathematics courses which are not primarily taught by fulltime faculty have a standardized calendar and online homework templates. This was not the case for STAT 1100. There had been intermittent meetings of instructors for the introductory statistics courses convened by Clair or Druschel, but no uniform structure had been created for the courses. Part of the impetus for the renewal of STAT 1100 was complaints by instructors at the meetings.

Through the second pilot study of the revised STAT 1100 course taught by adjunct and graduate student instructors, it became clear that the nature and rationale of the course needed to be better communicated to prospective instructors. In subsequent semesters the training occurred during multiple meetings in addition to impromptu hallway conversations, emails before and during the semester, and shared course materials. Additionally, Druschel often observes STAT 1100 instructors and so she can advise them on the course structure and explain what to expect during student small group interactions. She also served as a faculty mentor for three graduate students who enrolled in the CTTL program described above who also taught STAT 1100.

There are certain aspects of the course that are new to many instructors. These include a consumer-based, non-computational statistics course with more emphasis on analysis and interpretation, the partially flipped classroom model, the emphasis on projects including the use of real-world health care data, and the reports on articles in fields that instructors may not be familiar with. Each of these aspects are addressed during the beginning of the semester meetings. The rationale for these course components is shared with the instructors along with practical tips for facilitation. Discussions continue during follow-up meetings throughout the semester. There is also a webpage with instructor resources addressing all of the course components.

While the projects have been a significant factor in the redesign of STAT 1100, it has been the hope of the course developers that the course format and projects are a formative ground to which instructors can add their own instructional style. Over the years different instructors have included mastery quizzes or interactive Desmos slides. These ideas are available to instructors by accessing a dedicated resource website. With the project revisions almost complete, the next area of focus will be to formalize the instructor training process.

Instructor and Client Discipline Feedback

At the end of Fall 2019, a poll of course instructors revealed that 100% of the instructors thought that teaching the course using small in-context group projects enhanced student learning. They also reported that they would be more inclined to use active learning techniques in future courses. In addition, 71.4% of the respondents stated that the group article project and the projects using the Hospital Compare data enhanced student learning. The instructors who were less on board with the projects tended to have less experience with active learning. Two instructors noted that they 'really enjoyed' teaching statistics this way; another expressed initial skepticism with the course format, but now believes it is a very effective system.

From Spring 2020 to Summer 2021, due to the COVID-19 lockdowns, we were only able to provide minimal support to instructors and also only received minimal feedback from them. For Fall 2021 courses, the feedback from the instructors, including the chair, was very positive. One said they "had a blast teaching the course" in spite of being initially concerned about teaching a consumer-based statistics course. Both instructors reported that students seemed to enjoy the projects. With the return of in-person formal instructor meetings, the collection of additional data from instructors and students, as well as opportunities for impromptu hallway discussions concerning the course will continue to advance this project.

The stakeholders' meeting in Fall 2020 was attended by faculty representatives from almost all partner disciplines whose students take this course. Information about the course structure, student projects, and data on student performance and polls was presented to the attendees. There was a wildly enthusiastic response from the stakeholder representatives. Suggestions of ways stakeholders could contribute to the course were identified along with ideas on ways to promote statistics with the student population taking the course. Ideas included providing a bank of articles for student article reports, including articles written by the healthcare faculty, creating short videos about how statistics is used in the professions and by students in their senior projects.

Faculty Roles, Course Sustainability, and Future Growth

Druschel was the main innovator of the course renewal, and, with valuable input from Radler, designed the projects and course structure. She regularly discusses the course with instructors, collects and analyzes course and instructor data, makes revisions and updates to projects, and is involved in cross discipline presentations and conversations. She also organizes meetings for the graduate students and instructors and works with them on course data analysis, project revisions, and presentations.

May coordinates with the department on the efforts to institutionalize the course reform. His goal is for the STAT 1100 renovation project to reach a point of stability, so the efforts of the renovation are not lost when Druschel needs to move on to a new project. As lower division supervisor in the department, May makes teaching assignments with a view to supporting the project, development of graduate student instructors, and facilitating discussions both in the department as a whole and between the department and client disciplines at appropriate times. His experience in SUMMIT-P has directly and indirectly kept this project on track. In particular, his experience with collaboration and outreach has been essential. He motivates and encourages team members when there are stumbling blocks in this momentous project that require revisions and adjustments.

Associate Dean for Student and Academic Affairs in the Doisy College of Health Sciences, E. Gockel-Blessing, is the lead contact for the partner disciplines. She represents the needs of the partner disciplines and, when necessary, includes faculty from other colleges in meetings and assigns tasks as part of the collaborative effort. Her knowledge about the college programs and the students' needs has been invaluable. She has been the main organizer and the driving force behind the statistics stakeholder meetings.

Course sustainability has been reinforced by enlisting the support of the mathematics department and the departments of client disciplines. The client disciplines are, by all accounts, very satisfied with the course and are interested in contributing support to it in different ways. The mathematics department has been supportive by providing funds to hire graduate students to help with projects and also providing additional support and encouragement.

Furthermore, course sustainability is built into the course through the multiple revisions to course projects including use of content from a wide variety of partner disciplines. This allows for portions of projects to be removed as needed. In addition, support structures have been developed, including the webpage of instructor resources and the meetings to prepare instructors to teach the course. These structures have been instrumental in creating a community of these instructors. As one indication that we are well on the road to sustainability, one instructor noted that they had never taught such a well-organized course designed for multiple sections. Another instructor likes the projects so much that they want to use a similar course format for a statistics for social justice course. The development of such a course would substantially add to the pool of quantitative reasoning courses appropriate for liberal arts majors, as well as add to the sustainability of the current course.

Ongoing sustainability needs consist of updating projects as the data and websites change, continuing improvements to the instructors onboarding process, and further development of the instructor community. This approach requires more instructor involvement than a routine course. This is a significant factor for adjunct instructors and graduate teaching assistants. The materials are available. The main issues are with instructors taking the time to adequately review the material and incorporating a more active approach to both teaching and assessing course content. Each of these items have potential solutions including developing detailed guides for the projects, providing additional coaching and training on active teaching and the flipped classroom model, developing apps to allow students to interact directly with the Hospital Compare data (CMS, 2022a; 2022b) and perhaps even check their work.

Future growth areas that have been discussed with the client disciplines include the development of videos of interviews where students or faculty talk about their use of statistics in senior projects, discipline-specific courses, or their profession and incorporating faculty-selected articles in the bank of articles for report projects. This will further help healthcare students appreciate the role of statistics in their fields. We are also investigating formal training for instructors of the course. This could include a small module which briefly introduces instructors to the typical training or curriculum for the healthcare student. Critical to the above efforts are the guidance and connections that Associate Dean Gockel-Blessing provides. Future growth areas for Druschel and May include analyzing and collecting more data on the course and collaboration on the development of a social justice version of the course.

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Author Note

Individuals interested in more information about the projects or developing a similar course are welcome to contact the authors: Dr. Kimberly Druschel, kimberly.druschel@slu.edu, Dr. Elizabeth Gockel-Blessing, elizabeth.gockelblessing@health.slu.edu, or Dr. Mike May, mike.may@slu.edu

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An Examination of Factors that Support Sustainable Cultural and Curricular Change in STEM Teaching and Learning

Erica Slate Young
Appalachian State University
slateer@appstate.edu

Peaches Hash
Appalachian State University
hashpe@appstate.edu

Sarah Schott
Duke University
schott@math.duke.edu

Jack Bookman
Duke University
bookman@math.duke.edu

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Abstract

Using a mixed-methods design, this body of work from the SUMMIT-P consortium explores possible effective conditions for the sustainable reform of STEM teaching and learning at the collegiate level. A model of catalysts for successful and sustainable change is proposed, based on five years of data collection and observations. These catalysts include institutional support, intrinsic and extrinsic motivation of faculty involved, measures of student success, institution size, prior faculty experience, faculty buy-in, and institutional culture. The discussion ends with a delve into the potential broader impacts of this work. For example, this model may help institutions better understand how to implement curricular change more effectively.

Keywords

evaluation, STEM teaching, sustainable change

Since 2016, the members of A National Consortium for Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnership (SUMMIT-P) have been working to establish interdisciplinary Faculty Learning Communities (FLCs) in order to revise and improve the teaching of mathematics in lower division college classes. (For additional background information and details regarding the SUMMIT-P consortium, we refer the reader to Ganter and Haver (2020).) The changes sought as part of the SUMMIT-P project are not merely revisions to the content that is taught, but also to how the content is taught.

The term *curriculum* is interpreted in many different ways. Some consider the term curriculum to refer strictly to what is taught, while others consider it to be a combination of what is taught and how it is taught; we take the latter view. We therefore see curricular change as change within course materials as well as change in teaching practices. Curricular materials are more tangible than faculty professional development, and so are often the focus of many reform efforts. The development of curriculum materials alone may not have a lasting impact. It is difficult to ensure fidelity to materials without the corresponding faculty professional development. The materials themselves may remain in courses, but may not be implemented with an adequate focus on active learning. More than just seeking to develop new curricular approaches, the members of the SUMMIT-P consortium are working to change the faculty teaching practices to promote more active learning strategies. In some cases, this also requires changing the *culture* of their departments or institutions. Here we use the term *culture* as defined by Reinholz and Apkarian (2018), "[c]ulture is a historical and evolving set of structures and symbols and the resulting power relationships between people," (p.3). The *structures* referred to here are "the roles, routines, and practices of a department," (Reinholz & Apkarian, 2018, p. 5); these structures are contingent on the *symbols*, "which are the norms, values, and ways of thinking in a department," (Reinholz & Apkarian, 2018, p. 5). These definitions of curriculum and culture have guided the work we present below.

Over the past five years, we, the research team, collected responses from participants to periodic prompts, participated in site visits, and conducted interviews and focus groups. Using a mixed-methods design, our analysis of data collected as part of the research and evaluation of the SUMMIT-P consortium explores possible effective conditions for the sustainable reform of STEM teaching and learning at the collegiate level. From these data collections and observations, we developed a model of catalysts for successful and sustainable change that we will discuss in this paper.

Research on Change Strategies

Henderson et al. (2011) conducted an extensive literature review of journal articles published between 1995 and 2008 that discussed promoting change in instructional practices of undergraduate science, technology, engineering, and mathematics (STEM) courses. They categorized their findings into four broad categories of change strategies. The first category is "Individual/Prescribed," which focuses on disseminating curriculum and pedagogy through "communicating the change agent's vision of good teaching to individual instructors" (p. 2). The change agent promotes change by using their specialized knowledge to show others new ways to create curricula or teach. Henderson et al.'s (2011) second category is "Individual/Emergent," a category that focuses on developing reflective teachers by encouraging teachers "to use their own knowledge/experience/skill to improve their instructional practices" (p. 10). The change agent encourages teachers and supports reflective practices as they identify areas they wish to improve. The third category, "Environments/Prescribed," focuses on enacting policy. This type of intervention emphasizes "developing appropriate environments (e.g., rules, reward systems, reporting requirements, investments in support structures) to facilitate instructors engaging in specific or desired activities" (p. 11). The change agent develops new environmental elements that promote new behaviors or attitudes, leading to changes in instruction. Under this category, change agents have a specific vision that educators work towards developing. Henderson et al.'s final category is "Environments/Emergent," which focuses on a shared vision between stakeholders. The change agent works towards empowering individuals "to come together and work toward collectively envisioned change (p. 12).

In their review of articles, Henderson et al. (2011) found that there were similar numbers of articles that fit into the Curriculum & Pedagogy, Reflective Teachers, and Policy categories, but fewer that fit into the Shared Vision category; however, the scholars also noticed divides in categories based on the types of research being conducted. Henderson et al. (2011) note that STEM education researchers write about disseminating curriculum and pedagogy when they refer to change, while faculty development researchers focus on change that develops reflective teachers. Higher education researchers, in contrast, largely focus on change that results in enacting policy. Henderson et al. (2011) also highlights that only 21% of the articles they reviewed presented strong evidence of success or failure of the change strategy; however, the scholars were able to conclude from their literature analysis that effective change strategies align or seek to change beliefs, include long-term interventions, and design strategies for complex systems.

Effective change strategies may include specialized models designed for professional growth. In their research with K-12 teachers, Clarke and Hollingsworth (2002) state that change is often viewed as something "done to teachers" (p. 948) where teachers have little agency in the process. The effect of this lack of agency is that less change occurs because teachers are not invested. Clarke and Hollingsworth (2002) express that professional development designed for change must move away from the deficit-training-mastery model to one where teachers are active participants in learning and reflection. They propose the Interconnected Model as a solution to teachers' lack of agency. The Interconnected Model involves change occurring through mediating processes of reflection and enactment in four domains that encompass teachers' worlds: "the personal domain (teacher knowledge, beliefs, and attitudes), the domain of practice (professional experimentation), the domain of consequence (salient outcomes), and the external domain (sources of information, stimulus or support)" (p. 950). These domains are categorized into two types, the external and the personal. The Interconnected Model encompasses the complexity of professional growth by identifying multiple growth pathways between domains. It is a nonlinear model that "recognizes professional growth as an inevitable and continuing process of learning" (p. 950).

Gess-Newsome et al. (2003) also promote a change model that involves viewing teachers as dynamic individuals. The Teacher-Centered Systemic Reform model (TCSR) is a framework to understand how teachers' beliefs are shaped and may influence their professional behaviors. The TCSR involves "teaching context, teacher characteristics, teacher thinking, and their interactions as influential factors in attempts to implement classroom reform" (p. 731). Gess-Newsome et al. (2003) propose that interventions, teacher dissatisfaction, and changes in personal practical theories are the most impactful influences on the enactment of reform. When teachers experience pedagogical and contextual dissatisfaction, there is an opening for fundamental change.

Change strategies facilitate growth in groups of educators as well as individuals. Stein and Short (2001) note the benefits of working with faculty in collaborative groups, explaining that “[g]roup work can be superior to individual work because group products may exceed both the potential of the most talented participant and the potential of the separate efforts of group members working individually” (p. 419); however, the scholars also recognize that personal barriers such as lack of interpersonal skills and style, as well as social and psychological forces, can negatively impact group collaboration. To make group collaboration a positive, beneficial experience, Stein and Short (2001) recommend that educational leaders define the type of collaboration teachers will participate in beforehand and consider strategic decisions such as pacing of interactions, acknowledging differences within the group, and using innovation to increase chances of the collaboration’s success. Beach and Cox (2009) sought to develop the teaching abilities of junior faculty within a consortium of institutions through faculty learning communities. Beach and Cox (2009) define FLCs as “safe, supportive communities in which faculty and professional staff can investigate and take risks in implementing new approaches to teaching and by increasing the collaboration and coherence of learning across disciplines,” (p. 7). Each FLC was made up of cross-disciplinary faculty communities of 8-12 people that focused on an active, collaborative curriculum designed to enhance undergraduate learning. Beach and Cox (2009) found that the faculty who participated in the FLCs reported “at least moderate changes in student learning 1-3 years after their participation” (p. 24). The faculty were trying different approaches to teaching and noted impacts on student learning that they credited to their participation.

Bolman and Deal (2008) recognize that leaders often contribute too few new or innovative ideas when facing organizational problems and challenges, instead relying on habitual responses. These habitual responses lead to a limited cognitive perspective, where leaders can only see one way to handle a particular problem. The result is that leaders are less capable of responding to complex problems. Bolman and Deal’s (2008) solution is to teach leaders to reframe so they can approach problems in a new light. Educational leaders seek to help teachers develop through change theories that will lead to programmatic change.

The Framework for our Exploratory Research

We would like to make clear that the work we present here is the result of exploratory research used for generating hypotheses. The model we propose is based on our research conducted using a grounded theory approach (Glaser & Strauss, 1967), utilizing a small sample size and largely qualitative methods. Our subjects were the PIs and co-PIs of the SUMMIT-P consortium, but we also observed other elements within the scope of the project. We participated in site visits to each of the institutions, where we were able to observe classes taught by SUMMIT-P faculty. During site visits, we had the opportunity to conduct focus groups with students in the SUMMIT-P classes and have informal conversations with other faculty and administrators at the institution. We were also able to use our time during the annual SUMMIT-P meetings to conduct focus group sessions with the participants in the project. These elements all served as supplementary data giving us insights into some of the unique cultural aspects unique to the individual institutions.

Our primary source of data from the participants came in the form of the Evaluation Portfolio (Slate Young et al., 2020). Several times per year, we would ask the SUMMIT-P participants to respond to a reflective discussion prompt. Each prompt was tailored to give us insights into individual faculty members' perspectives on their efforts related to the SUMMIT-P project at their institution. For example, we posed this prompt near the midpoint of the project:

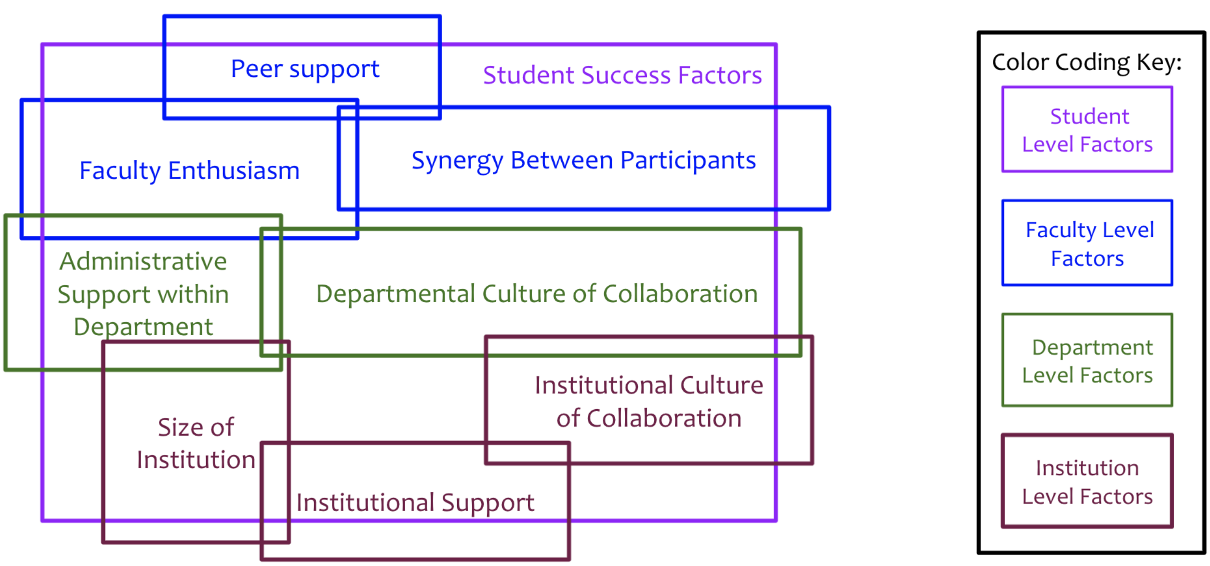
> *Think back to your early experiences teaching compared to now. Describe a way in which your teaching has changed. What were your reasons for that change? (Tell us the story about how that change happened.)*

We examined the responses to each prompt looking for trends or commonalities in the responses. We were able to then use observational data from site visits and the annual SUMMIT-P meetings to triangulate our results.

An Emergent Model of Sustainability Factors for Interdisciplinary Collaborations

From our examination of the qualitative data gathered in the site visits, portfolio responses, focus groups, and other evaluation activities discussed above, we concluded that some institutions were more successful in implementing changes and were more likely to sustain those changes. We grouped the nine institutions into three tiers – successful, moderately successful, and struggling – and then listed which observations and factors contributed to this classification of their level of success. This evaluation led us to propose a model of interlacing factors described below in Figure 1. We would like to emphasize that each institution in the consortium had its own strengths and challenges and therefore the model is very much context dependent. Our model described below illustrates some of the primary factors we observed that contribute to the success of a project, however, we would be remiss if we did not acknowledge the caveat that we observed one element is constant across all programs: there needs to be a powerful catalyst to begin the change process and most often this is in the form of one dedicated, devoted leader. The efforts of this leader will not be sufficient to sustain the change; sustainable change requires more than the efforts of a single faculty member; how much more is required, depends on the institution.

Figure 1
An Emergent Model of Factors Contributing to Sustainability of Interdisciplinary Collaborations



Description of Sustainability Diagrams

The model in Figure 1 describes four primary factors that we theorize have an impact on the sustainability of a project within an institution. In this diagram, we attempt to capture the idea that many of these factors interrelate with one another, but these interactions are complex and difficult to capture. For instance, in the diagram above, we show that student success factors overlap with all other factors because, often, these student success factors impact, or are impacted by, the level of support from other faculty, from the department, and from the institution. This is given as a hypothetical example of the relationships of the items in the diagram (e.g., overlap). Each institution would have its own unique model, with the various factors overlapping in different ways. Below, we provide our working definitions of each of the factors included in our model and offer vignettes solicited from participants at various SUMMIT-P institutions to further illustrate the definitions.

Student-Level Success Factors

This factor encompasses several aspects of how the project impacts students. The focus of the SUMMIT-P project is primarily on faculty development; however, a positive impact on students is the ultimate goal and certainly plays a role in the potential for sustainability of the project. Student Success factors include, but are not limited to, overall student performance in SUMMIT-P related courses (i.e., grades, D-F-W rates, etc.), student performance on assessments, student performance in follow-on courses, and attitudinal aspects such as students' perceived relevance of the content, student attitudes toward the content, and student participation and engagement in class.

Vignette – Importance of Student Success Factors

At Lee University, as part of the requirements of our program, all elementary education majors must pass a "Mathematics Manipulatives Assessment." In this assessment, students are asked to demonstrate various mathematical principles using commonly available manipulatives used in elementary classrooms (Cuisenaire rods, unifix cubes, pattern blocks, etc.). Historically, the first-time pass rates for this assessment were relatively low and math anxiety was very high. This was an issue discussed by the mathematics and education faculty at the start of the SUMMIT-P project at Lee University. In response to this issue, the mathematics faculty began incorporating manipulatives into mathematics courses for elementary education majors. Education faculty also emphasized the use of manipulatives in an elementary teaching methods course. As a result, the first-time pass rates on the Mathematics Manipulatives Assessment began to improve. Because of the evidence gathered of the direct positive impact on students, there is a greater level of buy-in from the mathematics faculty teaching the course(s) for the prospective elementary teachers. This change will likely be sustained past the life of the SUMMIT-P project.

Faculty Level Factors

Peer Support. If a project is viewed favorably by peers, faculty are more likely to expend effort toward it. With the varying expectations of teaching, research, and service placed on faculty members, one is rewarded for time spent on activities that are deemed worthwhile. This is especially true for pre-tenured and non-tenure track faculty. Peer support for the project also includes faculty buy-in and the willingness of peers to adopt pedagogical changes associated with the project.

Enduring Faculty Enthusiasm. There must be a critical mass of faculty with the experience, mental energy, and time commitment available to devote to the project. A project of this magnitude cannot be sustained by the efforts of a single faculty member, regardless of how committed that faculty member is to the work. This is more than a curriculum development project – it is a faculty development project. The faculty member's level of experience with curriculum projects is another important element. Participating faculty must believe in the value of the project and feel that they have the ability to make the changes required for the project. In some of our observations, the presence of this factor was a primary reason for success. Conversely, in at least one case, the absence of this factor was a reason for the lack of progress.

Synergy Between Participants. This particular project involved the collaboration of faculty across disciplines. The most successful institutions worked to establish a steady line of communication between participating departments. In particular, the development of an FLC proved to be particularly successful in making participants feel accountable toward one another, as well as toward the project. Also, if the faculty working together have certain collegial qualities that promote harmony within the team, the project is more likely to be sustainable.

Vignette – Importance of Faculty Level Factors

At Augsburg University, the faculty involved in the SUMMIT-P project had all had extensive teaching experience, ranging from 14-35 years each. Several of us have been involved with curriculum reform projects. Academic departments are small and the institution is based on a teacher-scholar model, that is, the teaching is a high priority for tenure and other reviews and scholarship focuses on teaching and student learning. Members of the team have worked together for 14 years, two for 33. The university values and rewards interdisciplinary work of many kinds. After years of working together, the mutual respect we have for each other has helped to promote the synergy of the group. We intend to continue using the products we developed, incrementally improving, evolving, and replacing them over time. We will continue to collaborate and are discussing possible collaboration on the mathematics in the General Chemistry course which has been identified by the university as a student success roadblock.

Department Level Factors

Administrative Support (within department). In order for a project such as SUMMIT-P to be sustained, there must also be administrative support factors at the department level. These factors include the ability for course changes to be codified into the course description and/or syllabus for a particular course, and accommodations made in course scheduling to allow for consistent, and predictable scheduling of faculty, including non-tenure track faculty, teaching the impacted courses.

Departmental Culture of Collaboration. In departments where collaboration among colleagues was already an established practice, the work done as part of SUMMIT-P was a more organic process. However, in departments where collaborative work was not the norm, extra efforts needed to be made in order to promote collaboration. The peer support element discussed above is strongly tied to this factor. In addition to the culture of collaboration among faculty within a department, there should be a perceived value of interdisciplinary collaboration with other departments, and these collaborations should be valued by the department when it comes to performance reviews.

Vignette – Importance of Department Level Factors

At one SUMMIT-P institution, the project originally planned on focusing on integrating biology concepts into the calculus curriculum. The PI was expected to be one of the calculus instructors and therefore had the authority to pilot the initial changes within the sections they taught. After the initial planning phase, before the curricular changes were implemented, the PI was informed that they would not be teaching calculus. Therefore, the work for SUMMIT-P needed to be re-framed for a new mathematics context, causing a delay in the implementation. Although there was a loss of momentum, the team was able to revise their plan, including both the content and project timeline. This is an example of how competing administrative pressures in a department serving large numbers of students can create difficulties.

Institution Level Factors

Size of Institution. Most large universities are siloed (within schools or departments). This can potentially impact the ability to collaborate. Conversely, in some cases, smaller institutions have more opportunities for cross-discipline collaboration.

Institutional Support. This factor covers a wide variety of elements. A project is more likely to be successful and sustainable if the institutional priorities concerning undergraduate education are conducive to interdisciplinary collaboration. Different institutions prioritize research, graduate education, and undergraduate education in different ways. If an institution has a history of innovative support for faculty, such as an active Teaching and Learning Center, support and/or incentives for collaboration (e.g., FLCs), and support or incentives for curriculum innovation, then that works in favor of projects like SUMMIT-P. For these projects to be successful and sustainable, educational innovation should be recognized and supported in a meaningful way at the institutional level (e.g., financially or credit towards promotion).

Institutional Culture of Collaboration. Much like the "department culture of collaboration" factor (see Figure 1), an established culture of collaboration in an institution contributes to the success and sustainability of a project like SUMMIT-P. Across different departments in the institution, the following questions should be addressed to gauge and improve the institutional culture of collaboration:

- Do faculty regularly collaborate to share ideas about teaching or research?
- In addition to the culture of collaboration within an institution, is there a perceived value of interdisciplinary collaboration across departments?
- Are these collaborations valued by the institution when it comes to decisions about reappointment, promotion, tenure, and post-tenure reviews?
- Logistically speaking, is there time and space allocated for faculty collaboration?

Vignette – Importance of Institution Level Factors

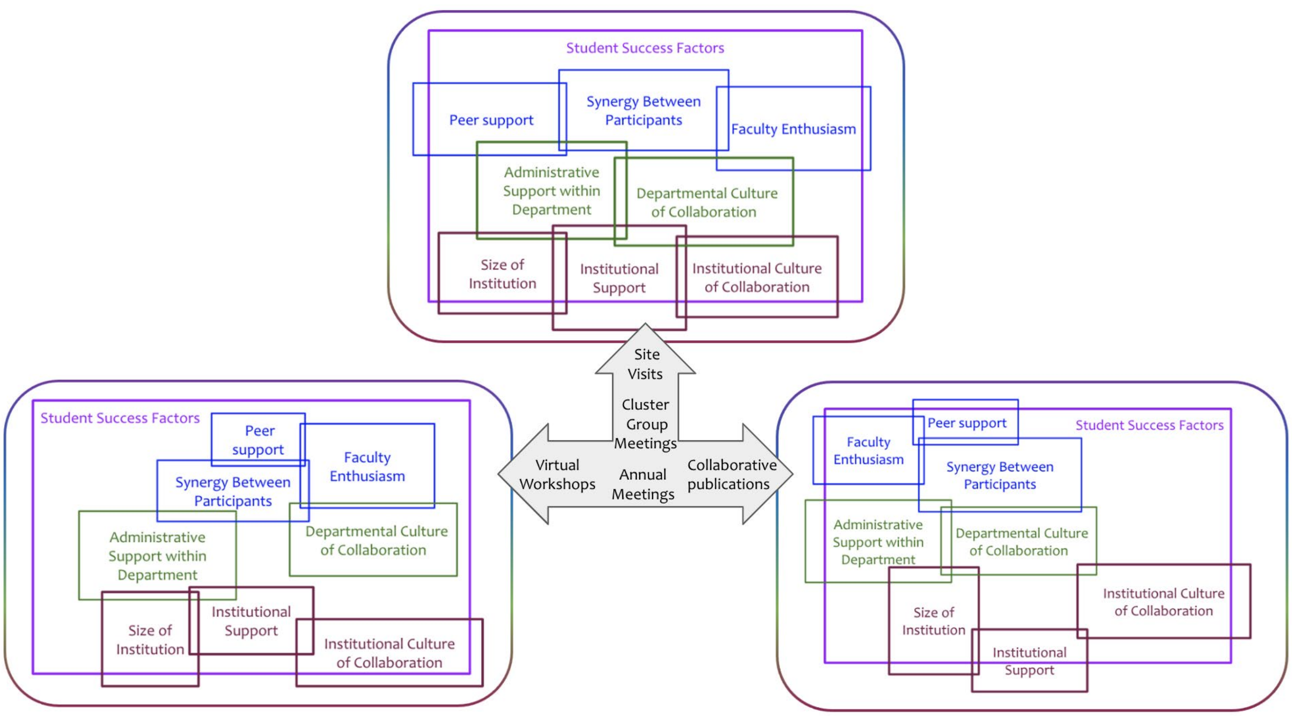
For many years, FLCs have been part of the institutional culture at Ferris State University. There is a dedicated space in the Ferris Library for Information, Technology, and Education set aside for FLCs to meet. The university offers professional development incentive funds for participants who successfully complete an FLC. Therefore, our participation in the SUMMIT-P consortium fit naturally into that structure. Also, our institution has prioritized quantitative literacy across the curriculum in the general education program, therefore the collaborative work done for our SUMMIT-P project aligns well with the institutional goals. These factors will help to promote the sustainability of our project.

Multi-institution Factors

In addition to the work being done at individual institutions, the SUMMIT-P consortium structure provided a catalyst for work to be done across multiple institutions. The consortium structure also may have helped keep the momentum going at the institutions because of the accountability that comes with being part of a larger project. In addition to the FLCs that were formed, the site visits, Principal Investigator meetings, and the annual consortium meetings helped create a sense of community of practice which in turn fostered the collaborations. The diagram in Figure 2 illustrates the factors outside of a single institution that impacted the collaborative work across institutions within the SUMMIT-P consortium. Each institution in the diagram is represented with a slightly different version of our model to denote that each institution has its own unique internal factors. For simplicity, we limited the diagram to three institutions rather than including all 12. The arrows represent the activities within the SUMMIT-P project that were the most impactful in promoting multi-institutional collaborations: site visits, cluster group meetings, virtual workshops, collaborative publications, and the annual SUMMIT-P meeting.

Figure 2

Multi-Institutional Factors Contributing to Sustainability of Interdisciplinary Collaborations



Vignette – Importance of Multi-Institution Factors

Norfolk State University (NSU) has been a SUMMIT-P institution since the project was first funded in 2016. Two years into the project, after the departure of co-PIs from the mathematics department and its partner discipline, engineering, NSU found its project in a state of disarray. The leadership team at NSU was overwhelmed with no clear direction to follow. A new leadership team was formed to rejuvenate the project, but there was one nagging question that bothered the new team members. "How do we jump start the project and what direction *should we take to make up for the lost time?" This question was the main topic of discussion at a two-day site visit hosted by NSU in the Spring of 2019. The visiting team consisted of two SUMMIT-P faculty from Virginia Commonwealth University (VCU) and two members from the project management team. In order to assist NSU's leadership team with their dilemmas, the site visit team recommended that, as part of their SUMMIT-P project, NSU offer a number of summer opportunities to members of mathematics and engineering faculty to collaborate on creating interdisciplinary examples. These summer collaborations strengthened the relationship between faculty in mathematics and engineering and ultimately enabled NSU to revive its project, develop effective materials, and contribute to the overall SUMMIT-P project.*

Discussion and Conclusion

As stated earlier, this emergent model is based on our exploratory research. Future work needs to be conducted to verify our model and to add a deeper understanding of how the pieces work together. We have a small sample size and therefore our generalizability is limited. However, we see this framework as a starting point for understanding the various factors that contribute to the sustainability of innovations in educational settings. As it stands, our model could be used by departments or programs as part of a self-assessment instrument. It would be a useful reflective exercise to examine how the factors at each level interact and overlap within a particular context. For instance, in our model, we hypothesize that student success factors overlap with all other factors because student success is a driving force at institutions of higher education. Yet, in some cases, other factors, such as departmental culture of collaboration, might not be as crucial for sustaining innovation. Faculty enthusiasm hinges on the perceived benefit from the work at hand, which is often more than just monetary compensation (positive impacts on students, "credit" towards promotion and tenure, professional growth, etc.). Each of the factors in our model are complex entities that will vary greatly depending on the institutional environment; the necessary and sufficient elements for sustainable change vary depending on the context. Making lasting change in an educational setting is a complex undertaking, requiring the buy-in and support from many interlacing elements. As Rienholz and Apkarian (2018) imply, ignoring these interlacing elements will impact the sustainability of the desired change. We present our model as a possible organizing structure to help those seeking to implement an innovation to consider the factors that may play a crucial role in the success of their projects. In closing, we are reminded of the proverb, "It takes a village to raise a child." We could rephrase it to be, "It takes a community to support an innovation."

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AN EXPLORATION OF THE USE OF SCIENCE SPECIALISTS AND ELEMENTARY STUDENTS' SCIENCE ACHIEVEMENT

Wesley Roach
Liberty University
waroach@liberty.edu

Jillian L. Wendt
University of the District of Columbia
jillian.wendt@udc.edu

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ABSTRACT

The purpose of this causal-comparative study was to examine the effect of using science specialists in elementary schools on science achievement scores. The sample population consisted of 282 fifth grade students enrolled in Georgia public schools. The data for this study was collected from four public elementary schools' end-of-year state assessments and analyzed as archival data. An analysis of covariance (ANCOVA) was used to determine if there was a difference between science achievement scores in elementary schools that use science specialists compared to those that do not. Results indicate that no statistically significant difference exists between the science achievement scores of students enrolled in schools that use science specialists for science instruction compared to those that do not. Implications of the findings are discussed relating to education practice, administration, and needs for future study.

KEYWORDS

science specialist, generalist, instruction, elementary science, science achievement

Within the field of education, it is widely recognized that science literacy is imperative to preparing a citizenry capable of ensuring globally competitive progress as well as scientifically based decision making. Over 60 years ago, President Dwight Eisenhower addressed the U.S. Congress about the importance of science education stating, “if we are to maintain our position of leadership, we must see to it that today’s young people are prepared to contribute the maximum to our future progress” (Eisenhower, 1958, p. 103). Over 52 years later, President Barak Obama (2009) echoed similar sentiments in his address to the National Academy of Sciences when he stressed that countries that provide the strongest education for their students will have a competitive advantage over other countries. It is well known that the wellbeing of the country is dependent on citizens being scientifically literate (Gibbons, 2003; Huderson & Huderson, 2019; National Research Council [NRC], 2013a, 2013b), and that literacy begins with strong elementary science education (Barak & Dori, 2011; Ravanis, 2017).

Unfortunately, the need for qualified people to enter career fields related to science far exceeds the current rate at which people are entering such career fields (Bureau of Labor Statistics, 2019; President’s Council of Advisors on Science and Technology [PCAST], 2012). Furthermore, reports indicate that U.S. students often lag in science performance behind their counterparts from other countries around the world (Kena et al., 2016; NRC, 2013b). The most recent available National Assessment of Educational Progress ([NAEP], 2021) report indicated that fourth grade students scored lower in science in 2019 as compared to 2015, indicating that students are still struggling with science achievement. To address the need for more qualified people to enter career fields related to science and to bolster the science achievement of U.S. students, there must be effective science instruction in elementary schools (Kier & Lee, 2017; Nelson & Landel, 2007; NRC, 2013a).

It has been demonstrated that students are more likely to develop stronger interests in science and to pursue more advanced science courses when they have been exposed to engaging science instruction in elementary school (Campbell & Chittleborough, 2014; Hanuscin, 2007; McGrew, 2012; McNeill & Pimentel, 2010; Smith et al., 2016). Furthermore, students who are given the opportunity to engage with authentic science practices are more likely to develop proficient scientific literacy (Diaconu et al., 2012; Jones et al., 2012; Qarareh, 2016). However, in many elementary schools, the time allotted for science instruction has historically been shortened to allow for an emphasis on subjects such as reading and mathematics (Banilower et al., 2013; Blank, 2013; Bybee, 2013; Milner et al., 2012; NRC, 2015; Olson et al., 2015). Studies indicate that many elementary teachers express a preference for teaching subjects other than science (Kirst & Flood, 2017; Scott, 2016; Wilson & Kittleson, 2012) and others may not feel that they are adequately prepared to teach science (Gillies & Nichols, 2015; Wendt & Rockinson-Szapkiw, 2018; Wilson & Kittleson, 2012;). Baldi et al. (2015) reported that 92% of the elementary teachers in their study were charged with teaching all subjects in a self-contained setting, meaning that they are not able to specialize in any one subject. This can be problematic when teachers are not provided sufficient training and supports to enable scientific expertise and development of content knowledge (Kier & Lee, 2017; Schwartz & Gess-Newsome, 2008).

Conceptual Framework and Background

The teaching of science is distinguished from other subjects because of its unique nature. There are research-based strategies that may be employed to teach students to read (Walpole & McKenna, 2017). Algorithms may be learned, and proven approaches to problem solving may be applied to learn mathematics (Krawec & Montague, 2014). Themes from the human experience may be reinforced in social studies to help prepare students to be productive citizens in our democratic society (Pryor et al., 2016). But effective science teaching is complex in the sense that science instruction that is oriented only around the memorization of subject content does not lead to the kind of deep understanding of science that students need to acquire to become scientifically literate citizens (Aydeniz et al., 2012; Steinberg et al., 2015). Teacher content knowledge and pedagogical prowess surrounding the effective implementation of science has been cited as a key indicator for the measurement of progress toward enhancing participation and success in K-12 science education (NRC, 2013a).

A pivotal publication, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Idea* (NRC, 2012) gave rise to the *Next Generation Science Standards: For States, By States* (NGSS), which in turn has helped to shape current reforms in K-12 science education (NRC, 2013b). The NGSS defines what should be learned by the time a student graduates from high school and, importantly, the fact that such learning must begin at a young age (NRC, 2013b). Thus, it is essential to consider what model of science instruction best meets the demands for effective and rigorous elementary science instruction that engages students and aligns with best practices, including standards, in science. Understanding the frameworks and models that support current science education efforts is important as it brings to light the need to ensure depth and breadth of knowledge of those who are teaching science in the field—thus, ensuring depth and breadth of students' science learning (Next Generation Science Standards [NGSS], 2013).

Effective science learning must engage students in ways that go beyond the mere memorization of science facts by emphasizing the practices and crosscutting concepts of science. One of the challenges for elementary teachers is that many of them have neither experienced nor been trained in these kinds of instructional practices (Olson et al., 2015; Steinberg et al., 2015). Furthermore, most elementary teachers have been trained to be generalists. That is, they are expected to teach all subjects to their students (Dejarnette, 2016; Schwartz & Gess-Newsome, 2008) and, thus, may not hold content expertise in all areas or perceive that they are knowledgeable in all areas. As the elementary classroom has been cited as foundational to the development of students' understandings of science as a practice (Kier & Lee, 2017), there is a continued need to explore methods for enhancing science instruction in the classroom and for providing such science expertise. One potential method for providing science instruction with increased expertise is the use of science specialists—individuals who have received degrees or enhanced training in science and who are tasked with teaching only science (Schwartz & Gess-Newsome, 2008).

The Use of Elementary Science Specialists

The literature supports that there are several barriers to the goal of effective science instruction and learning in elementary schools. Many elementary teachers express a preference for non-science subjects (Kirst & Flood, 2017; Marco-Bujosa & Levy, 2016; Scott, 2016) and often express a lack of confidence in the area of science content (Gillies & Nichols, 2015; Wendt & Rockinson-Szapkiw, 2018; Wilson & Kittleson, 2012). The amount of instructional time for science in elementary schools is often abbreviated to allow more time for teaching reading and mathematics (Banilower et al., 2013; Blank, 2013; Bybee, 2013; Milner et al., 2012; NRC, 2015; Olson et al., 2015). These factors, and others, may have contributed to the current state of science achievement for U.S. students, who score lower on some science assessments than many of their counterparts around the world (Kena et al., 2016). The National Academies of Sciences, Engineering, and Medicine (2016) highlighted the importance of scientific knowledge and scientific literacy for the purpose of preserving a democratic way of life and a vibrant economy.

In response to the need for more effective and rigorous elementary science instruction some elementary schools have turned to the use of elementary science specialists (Abell, 1990; Hounshell, 1987; Poland et al., 2017; Schwartz & Gess-Newsome, 2008; Williams, 1990). While the role and training of elementary science specialists varies from state to state or even from school to school (Brobst et al., 2017), they are typically charged with teaching only science and tend to have some additional training in the areas of science content or science instruction (Baldi et al., 2015; NRC, 2014; Olson et al., 2015), although the amount and type of training is not consistent from school-to-school. Claims have been made that elementary science specialists hold several advantages over elementary teachers who are generalists when it comes to effective science instruction, including a greater likelihood to have had more advanced training or degrees in science; a higher level of confidence in the field of science; a greater familiarity with science curriculum; and more time to prepare science lessons and to know students' needs in science (Brobst et al., 2017). Despite the advantages claimed for using elementary science specialists, only 26% of elementary students in the U.S. receive instruction from science specialists (Banilower et al., 2013).

While the idea of using science specialists to support the elementary generalist is not new and has been relatively widely employed, little research has explored the impact of science specialists on students (Levy et al., 2016). Thus, it is not currently known whether the use of science specialists has any impact on student learning and, importantly, student achievement in science. Studies that have examined the use of science specialists tend to have explored science specialists' development of identity (Kier & Lee, 2017), elementary teachers' perspectives surrounding the use of science specialists (Poland et al., 2017), and the impact of school supports on the teaching of science (Marco-Bujosa & Levy, 2016).

Of the few studies that have examined the effectiveness of using science specialists in elementary schools, the results have yielded conflicting conclusions (Levy et al., 2016; Marco-Bujosa & Levy, 2016;). For instance, when examining the impact of school supports on science teaching among schools utilizing science specialists, results indicated that myriad challenges exist in providing effective science instruction (Marco-Bujosa & Levy, 2016). More specifically, the science specialist model was not found to be sufficient in overcoming such school-based challenges. School conditions, such as administrative support, appeared to have a greater influence on science teaching than the use of science specialists alone, thus calling into question whether the use of science specialists was indeed beneficial.

Another study examined students' achievement scores on a state-mandated standardized test across schools that utilized science specialists compared to those who did not utilize science specialists over the course of four years (Levy et al., 2016). The results indicated that no statistically significant difference existed among students' scores when receiving science instruction from a science specialist compared to a generalist. However, when comparing mean scores, a small (although non-significant) difference was noted, with students who received instruction from science specialists scoring slightly higher than those who received instruction from a generalist.

As such, a dearth exists in studies that explore the potential impact of science specialists on student science outcomes. Researchers have continued to call for research that explores the use of science specialists in the elementary classroom (Brobst et al., 2017; Kier & Lee, 2017; Poland et al., 2017), especially in relation to student outcomes (Marco-Bujosa & Levy, 2016). Thus, the purpose of this causal-comparative study was to consider the following research question: Is there a statistically significant difference in the science achievement of fifth graders as measured by the Georgia Milestones Assessment System (GMAS) between schools where science specialists deliver science instruction and schools where generalists deliver science instruction?

Methodology

For this study a causal-comparative research design was used (Gall et al., 2007). The researchers collected archived science achievement data measured by the Georgia Milestones Assessment System (GMAS) for two consecutive years for students from two schools where science specialists (n = 2) were used to deliver science instruction and from two schools where generalists (n = 8) were used to deliver science instruction. The archived science achievement data included the students' scores from their fourth-grade assessment and from their fifth-grade assessment. The students' fourth-grade assessment scores served as a pretest for the purpose of controlling for students' prior science achievement.

The independent variable for this study was the type of teacher who delivered science instruction to the students. The nominal categories of the independent variable were science specialists (teachers who taught only science) and generalists (teachers who taught all subjects). Aligning with the research literature (Abell, 1990; Schwartz & Gess-Newsome, 2008) science specialists were defined as teachers with training in science content and pedagogy and who were tasked with teaching only science (Baldi et al., 2015; NRC, 2014; Olson et al., 2015). Since the type and amount of training that science specialists receive has not been consistent within the field or body of literature, the researchers confirmed that the science specialists utilized at the schools selected for this study had received science-specific professional training, including job-embedded training, and STEM professional development (e.g., STEM conferences and workshops).

The dependent variable for this study was students' science achievement – defined as the understanding of basic science concepts and the comprehension and application of scientific processes (Carrier, Thomson, Tugurian, & Stevenson, 2014). The dependent variable was measured by the GMAS. The GMAS measures students' proficiency in science concepts as well as their understanding of science practices as prescribed by the Georgia Standards of Excellence (GSE) curriculum guide (Georgia Department of Education [GaDOE], 2016a, 2017b). The use of a standardized assessment aligns with previous research that has examined the impact of science specialists on students' achievement outcomes (Levy et al., 2016) and, thus, was deemed appropriate for the current study.

Participants

Convenience sampling was used to select 282 fifth grade students' archival data for this study. Sample schools were selected by considering whether the schools used or did not use science specialists and by matching schools for similar demographics (gender ratio, race/ethnicity ratio, and socioeconomic status). After considering the available schools, four schools were selected—two that used science specialists and two that did not. In total, among the sample schools selected, there were 121 students from two schools where science specialists delivered science instruction and 161 students from two schools where generalists delivered science instruction. Thus, 121 of the students participating in this study received their science instruction during their fourth-grade year from a science specialist while 161 students participating in this study received science instruction from a generalist (see Table 1). None of the participants included in the sample had Individualized Education Plans (IEPs) and all of them had been in the same school for both their fourth- and fifth-grade years. The student population in the science specialist schools was comprised of 94% White students, 5% Hispanic students, and less than 1% multiracial students. The student population in the generalist schools was comprised of less than 1% Black students, 91% White students, 7% Hispanic students, less than 1% Asian students, and 1% multiracial students (see Table 1). The student population in the science specialist schools was comprised of 49% male students and 51% female students. The student population in the generalist schools was comprised of 48% male students and 52% female students (see Table 2). The student population in the science specialist schools was comprised of 67% economically disadvantaged students. The student population in the generalist schools was comprised of 56% economically disadvantaged students (see Table 3).

Table 1
Student Race/Ethnicity Summary for Study Subjects from Participating Schools

	Schools Where Specialists Teach Science			Schools Where Generalists Teach Science		
Demographic Description	**School A**	**School B**	**Total**	**School C**	**School D**	**Total**
Black	0	0	0	1	0	1
White	49	65	114	81	65	146
Hispanic	2	4	6	5	6	11
Asian	0	0	0	0	1	1
Multi-Racial	1	0	1	1	1	2
Other	0	0	0	0	0	0
Total	52	69	121	88	73	161

Table 2
Student Gender Summary for Study Subjects from Participating Schools

	Schools Where Specialists Teach Science			Schools Where Generalists Teach Science		
Gender Description	**School A**	**School B**	**Total**	**School C**	**School D**	**Total**
Male	23	36	59	47	30	77
Female	29	33	62	41	43	84
Total	52	69	121	88	73	161

Setting

The schools selected for this study were four accredited public elementary schools in rural northeast Georgia. The schools were selected because two were identified as having used

Table 3
Student Economic Status Summary for Study Subjects from Participating Schools

	Schools Where Specialists Teach Science			Schools Where Generalists Teach Science		
Economically Disadvantaged	**School A**	**School B**	**Total**	**School C**	**School D**	**Total**
Yes	37	44	81	45	45	90
No	15	25	40	43	28	71
Total	52	69	121	88	73	161

science specialists to deliver science instruction to students and two were identified as having not used science specialists to deliver science instruction based on surveys sent to school district principals. Additionally, as noted previously, the schools were similar in their racial and socioeconomic demographics. All four schools administered the GMAS each Spring semester as a means of assessing students' achievement levels based on the standards prescribed by the Georgia Standards of Excellence (GSE), which was the curriculum used in all public schools in Georgia at the time of the study.

Instrumentation

As noted, this study used the GMAS to measure science achievement. The GMAS was developed by the Georgia Department of Education (GaDOE) to measure students' learning and progress in each academic subject for grades three through eight (GaDOE, 2017a). The GMAS science assessment for fifth grade is comprised of 75 multiple choice items, 45 of which are criterion referenced, 20 of which are referenced to national norms, and 10 of which are field test items that do not count toward the students' scores. The test is taken in two sessions for which students are given 70 minutes per session. Students receive both a scaled score as well as an achievement level designation to indicate their level of science achievement. The three science domains represented on the test and their respective weights are Earth science at 30%, physical science at 30%, and life science at 40%. According to the GaDOE (2016b, 2017c) the GMAS science tests used for this study have median Cronbach's alpha reliability coefficients of 0.90 for the fifth-grade test, which was used for the dependent variable, and 0.91 for the fourth-grade test, which was used for the pretest for the purpose of a covariate.

Procedures

Principals at prospective schools were asked to complete a survey that described their schools' science instruction, including whether a science specialist or a generalist taught science. After institutional research board (IRB) approval was granted, schools were selected for the study. Two schools were selected where science specialists were used to teach science and two schools were selected where generalists were used to teach science. Since this study relied only on archival data that was accessible by request from the GaDOE it was not necessary to secure consent from the schools included in the study. However, a letter was sent informing principals that their schools' archived data related to students' performance on the GMAS science test would be used.

A request was made to the GaDOE for the archived GMAS scores for the students in the selected schools. The 2015-2016 school year fourth grade science scores and the 2016-2017 school year fifth grade science scores were requested. The GaDOE sent all requested data with all student identifiers removed and replaced with non-identifying student numbers. In addition to the science scores, the students' status as having diagnosed disabilities was also requested so that those students' scores could be removed from the data before any analysis of the data was conducted. Other requested data included students' gender, race, and free and reduced lunch qualification status. Any students who did not have test scores for both the 2015-2016 school year and the 2016-2017 school year were removed before any analysis of the data was conducted.

Analysis and Results

To test for statistical significance in the difference between the posttest mean scores for students who received instruction from a science specialist and students who did not receive instruction from a science specialist while controlling for prior science achievement, an ANCOVA was conducted. To control for threats to validity, two groups were used (Warner, 2013; one group of students who did not receive instruction from a science specialist and one group of students who did receive instruction from a science specialist, although variables were not manipulated given the ex post facto nature of the study. Prior to proceeding with the ANCOVA, assumption testing was conducted. The possibility of outliers was examined by visual inspection of boxplots and standardized values, and no outliers were identified. Kolmogorov-Smirnov was used to determine the tenability of the assumption of normality of the covariate scores and the dependent variable scores and was found tenable ($p = .200$), suggesting that there was an approximately normal distribution of each variable (Warner, 2013). A scatterplot was visually examined to verify the assumption of linearity between the covariate scores and the dependent variable scores and was deemed tenable. Levene's Test for Homogeneity of Variance was used to verify that there was similar variance of the dependent variable between each group and was deemed tenable ($F(1, 280) = 1.30$, $p = .256$).

The results of the ANCOVA revealed that there was no statistically significant difference between the posttest mean scores for the two groups while controlling for prior science achievement, $F(1, 279) = 0.56$, $p = .455$. Descriptive statistics are shown in Table 4.

Table 4

Descriptive Statistics for GMAS Science Scaled Scores (N=282)

GMAS Science Scaled Score	*n*	*M*	*SD*
2015-2016 (Pretest)			
Overall sample	282	524.54	40.61
Science specialist	121	512.99	39.04
Generalist	161	533.22	39.70
2016-2017 (Posttest)			
Overall sample	282	541.03	55.51
Science specialist	121	530.12	51.70
Generalist	161	549.24	57.00

While controlling for the effects of pretest scores which represented prior learning, the marginal science achievement score means for the group receiving instruction from science specialists was $M = 539.69$ ($SE = 2.68$, $n = 161$) while the science achievement score mean for the group not receiving instruction from science specialists was $M = 542.81$ ($SE = 3.11$, $n = 121$; see Table 5). These results indicate that students receiving science instruction from an elementary science specialist scored lower on the GMAS than students receiving science instruction from an elementary generalist. However, the difference in mean scores was small and statistically non-significant.

Table 5

Marginal Means for Posttest Scores by Type of Teacher Delivering Science Instruction

Specialist	Marginal Posttest Means	*SE*	*n*
Science Specialist	539.69	2.68	161
Generalist	542.81	3.11	121

Discussion

The results of the ANCOVA indicated that there was no statistically significant difference in the science achievement for students taught by science specialists and students not taught by science specialists in this study. This aligns with previous research that demonstrated no statistically significant difference in students' science standardized test scores when receiving instruction from science specialists as compared to generalists (Levy et al., 2016). In the previous study, Levy et al. (2016) asserted that there are several factors that impact science achievement, including the overall value placed on science in the school; the principal's support for the science program in the school; the resources made available for the science program; the quality of teachers in the school; the quality of instruction in the school; and the quantity of time allocated for science instruction in the school. Furthermore, Levy et al. (2016) and Marco-Bujosa and Levy (2016) supported that many factors may influence science achievement.

In the current study, it was hypothesized that the use of science specialists, given their exposure to job-embedded and STEM-related professional development, would provide an enhanced quality of science instruction to students, translating to higher student science achievement. Further, the current study also hypothesized that the inclusion of science specialists in the selected schools would serve as a demonstration of principals' support for science programs in the school. While these hypotheses may in fact be true, they did not yield a statistically significant difference in students' science achievement scores. Thus, the current study supports that the use of science specialists alone may not impact students' science achievement and that other factors, including the quality of instruction, specific instructional practices, and level and quality of principal support may indeed play a significant role. It is important to continue exploration to tease out individual factors that influence students' science outcomes and what specific role science specialists play in impacting such outcomes.

The findings of the current study also support the need to standardize what specific trainings, opportunities, or advanced degrees science specialists should hold to impart substantial impacts. In the current study, the science specialists used in the selected schools had not completed any coursework related specifically to a science education degree, nor did they hold any job experience in a science-related field outside of K-12 education, although they had engaged in job-embedded science professional development and STEM professional development opportunities. Given the use of archival data in this study, specific details related to the education, training, and experiences of the science specialists, including the number of years that they taught science and the specific methods of instruction they used, in the study was not available and, thus, serves as a limitation to the current study. Future study should explore these characteristics, perhaps through a quasi-experimental study. Further, this highlights a potential challenge within the body of literature and the relatively broad use of science specialists in that standardized requirements for science specialists have not yet been established. Thus, science specialists in one school might hold advanced expertise in science (such as advanced science education degrees) while science specialists in another setting may have only attended science-related workshops.

This is not to say that the use of science specialists is for naught, but rather that the current body of literature has not yet sufficiently defined the criteria required to be a science specialist, how science specialists are being used within schools, and what best practices effective science specialists might utilize. As reiterated within the literature, "one would expect specialists to have deeper science content knowledge and be able to engage students in higher quality science instruction due to some combination of interests and competencies coupled with the ability to focus either on fewer subject areas or on science exclusively" (Brobst et al., 2017, p. 1304).

For instance, previous literature that focused on engaging students in the practices of science found that authentic opportunities were more effective than traditional instruction that focuses primarily on the presentation of content knowledge (Diaconu et al., 2012; Harman et al., 2016). Studies have also supported that elementary science specialists, in general, utilize authentic learning opportunities more often than generalists, which may in turn lead to increased student engagement with science (Campbell & Chittleborrough, 2014). The use of archival data in the current study did not allow the measurement or examination of the specific strategies utilized in instructional delivery by science specialists or by elementary generalists. It cannot be assumed, then, that all science specialists are employing authentic learning opportunities in the classroom or, if they are, to what extent above and beyond what elementary generalists are currently doing. Study is needed, then, to identify specific practices that science specialists might use and, importantly, whether these practices differ substantially from the practices used by generalists.

In the current study, the effect of using elementary science specialists on science achievement was examined while controlling only for prior science achievement measured by one specific assessment—the GMAS. While the use of a standardized assessment to measure student outcomes, especially in relation to the impact provided by the use of science specialists, aligns with previous research (Levy et al. 2016), examination of other student outcomes may be beneficial in understanding whether science specialists influence students' interest in science, engagement in science, or other science outcomes.

Finally, the findings support the need for further examination to include a more specific definition of requirements that science specialists must meet, practices utilized by science specialists and elementary generalists, and the level and quality of supports provided to all educators charged with providing science instruction to elementary students. Evidence supports that science specialists may positively impact science attitudes, frequency of science instruction, interest in science, consistency in science curriculum, increased use of inquiry-based practices, and increased student science scores (Schwartz & Gess-Newsome, 2008). Thus, it would be prudent to determine what factors related to the use of science specialists are impactful given the historical use of science specialists to supplement and support elementary science education. Future study might also examine the impact of a larger number of science specialists and generalists.

Conclusion

The results of this study suggest that the impact of science specialists alone may not be sufficient to produce an increase in the science achievement of elementary students as measured by one science assessment and among one sample population. The results of this study align with other studies and suggest that schools seeking to improve the results of science instruction cannot focus solely on the type of teacher delivering instruction and, rather, should consider the specific practices used in instructional delivery and available resources to support all educators providing science instruction to students.

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