FROM CREATIVE IDEA TO IMPLEMENTATION: BORROWING PRACTICES AND PROBLEMS FROM SOCIAL SCIENCE DISCIPLINES

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ABSTRACT

By collaborating with partner disciplines, mathematics educators gain valuable insight into the perspectives and needs of their students. This insight can lead to improved coordination of content and methods between courses in mathematics and the partner disciplines. This curricular coordination not only invites students to apply their mathematical knowledge in their own professional contexts, but also allows students to communicate mathematical mastery in the language of their intended professions. In this paper, we discuss the challenges specific to developing a mathematics course in collaboration with partner disciplines, with particular attention to portability to a wide range of math instructors. We identify three key obstacles to portability: instructor familiarity with application domains, variety of assessment styles, and grading consistency. We describe how each of these obstacles is addressed and discuss strategies that have helped new instructors be successful in teaching the course.

KEYWORDS

course design, interdisciplinary collaboration, inquiry-based learning, mastery grading, faculty learning communities

"Math is everywhere!"—a well-intentioned sentiment to be sure, but one that is often met with skepticism from students. The problem, of course, is never in our ability to impose the language of mathematics upon the world but in the sometimes-lacking motivation for doing so. In this paper, we propose to invert the dilemma: instead of grafting the language of mathematics upon the world, what about teaching mathematics in the language of another discipline? We build on the model of Piercey and Militzer (2017), who showed that beginning and intermediate algebra skills could be taught effectively with business application problems and the use of Excel. This model is also found more broadly throughout the courses designed in the Synergistic Undergraduate Mathematics via Multi-Institutional Interdisciplinary Teaching Partnerships (SUMMIT-P) collaborative research project, which comprises mathematics and partner-discipline faculty members from nine colleges and universities (Beisegel & Dorée, 2020). The stated goal of SUMMIT-P is to promote collaborations with faculty from partner disciplines and create engaging courses that most effectively prepare students to make use of the mathematics that they study in course work in partner disciplines and within the workplace. We also draw heavily on the framework of the Curriculum Foundations Project (Kasube & McCallum, 2001), particularly its emphasis on the role of assessment in student learning.

This project is a collaboration between a mathematics department and colleagues in the disciplines of business, nursing, and social work. The course context of this project is Quantitative Reasoning for Professionals (QRP), a two-semester general education sequence in mathematics that is intended for students who struggled with algebra in high school. We designed this course to help students develop from simply solving problems to forming questions and inferences about the applications of algebra. We apply principles of quantitative reasoning to promote these habits of mind (Karaali et al., 2016). In collaboration with the partner disciplines, we developed a large number of algebra lessons with authentic applications in business, nursing, and social work, and we developed new types of assessments that coordinate with the applications in the lessons. For example, we assess mastery of several algebraic concepts through writing assignments such as funding proposals and budget projections developed in collaboration with colleagues in social work. As a result, QRP is a course that is situated in the language and practices of the partner disciplines and yet also achieves the goal of imparting mathematical skills. In this paper, we describe QRP and its development process and discuss the challenges particular to interdisciplinarity that arise when porting the course to new instructors.

In the first section, we describe the conception and development of QRP and the involvement of the partner disciplines and give a representative sample of lessons that we developed in collaboration with the partner disciplines. In the second section, we describe the structure of a typical lesson, give examples of typical assessment types, and discuss our grading philosophy of holistic or mastery-based grading. In the third section, we outline the challenges we have encountered in preparing and supporting instructors who are new to QRP and discuss strategies that have helped these instructors be successful in teaching the courses.

Course Description and Partner Disciplines

The QRP course sequence was developed by mathematics faculty at Ferris State University (FSU) through conversations with colleagues in several partner disciplines at the same institution over a period of six years. The project was initially developed in collaboration with the College of Business at FSU, which includes students in programs such as business administration, hospitality, and professional golf management. The mathematics focus of these programs is principally in their accounting and statistics. Piercey (2017) found that students in an early version of the course sequence scored higher on an algebra skills assessment than students in the parallel traditional algebra sequence. Motivated by this success, a faculty learning community was formed to broaden the scope of the course sequence to enroll students from the social work and nursing programs and to develop course materials applying algebra to these disciplines (Bishop, Piercey, & Stone, 2020). In order to identify the algebra-related priorities of our partner disciplines, we held a workshop in which partner-discipline faculty participated in a facilitated discussion about the mathematical needs of their students. This so-called "fishbowl" style of workshop was designed according to the SUMMIT-P collaborative research project (Hofrenning et al., 2020). The fishbowl workshop helped us to focus our course design on the following partner-discipline priorities. Our collaborators in social work were interested in preparing students to write profession-specific documents such as budget projections and funding proposals. Our collaborators in nursing gave dosing calculations, unit conversion, and exponential decay of drug concentration as the primary application areas of interest to their program.

Based on the feedback received from our partner disciplines, we developed many lessons that present algebra in the context of authentic applications to business, social work, and nursing. We drew on the recommendations of the Curriculum Foundations Project (Kasube & McCallum, 2001) to encourage students to interact with the instructor and learn from each other. All together, we developed over fifty lessons and over a dozen written and oral projects. The following are a representative sample of these lessons and projects.

- Fry efficiency: students construct a process to measure the efficiency and waste in french fry preparation at a fast food franchise. They have to translate their process into a formula that they program into Excel using the data in a given spreadsheet.
- Dosing calculations: students set up a series of proportions to determine the correct dose of a solution containing a certain concentration of medicine, using dosing guidelines by patient weight.
- Social justice: students analyze real United Nations data on human trafficking, identify trends, formulate recommendations to the UN, and create charts that support their recommendations.
- The credit card problem: given a fixed initial balance, a fixed interest rate, and a fixed monthly payment, students derive a formula for the length of time it will take to pay off a credit card.
- The birth control problem: students use an exponential model to predict the onset of menstruation after hormonal birth control is discontinued.

Implementation

Lesson Structure

The cornerstone of QRP is to help students learn to form questions and inferences about the applications of algebra. We accomplish this by creating lessons in discipline-specific scenarios with deliberate scaffolding to promote student inquiry. While our students do indeed find the inquiry-based applications engaging, this is only a secondary benefit of the lesson design. The primary purpose of these lessons is to provide an environment in which meaningful professional communication can ensue. It is much easier to promote inference in the context of an authentic scenario than in a purely symbolic-algebraic context. Since we view professional communication as an important vehicle of inquiry-based learning in QRP, we conduct the lessons primarily via group work and create frequent opportunities for the groups to discuss and debrief. For an extensive discussion of the use of active learning and inquiry-based methods in mathematics instruction, see Yoshinobu and Jones (2012) and Katz and Thoren (2017a; 2017b).

An active learning technique used by one instructor involves calling on a specific group using a group member's name. While the named student is implicitly encouraged to answer, the whole group is also given space to confer among themselves before offering a solution. Another instructor regularly asks students to rate their understanding with the numbers one through four, where a rating of four means that student feels prepared to teach the lesson to a peer, and a rating of one means the student needs help. This self-rating can help steer the class in a beneficial direction for the students and also helps the instructor form productive student groups.

The Fry Efficiency lesson is as a good example of a learning environment that promotes meaningful professional communication, here in the context of managing an Arby's franchise. The students are placed in groups and told that their "manager" has asked them to come up with a way to measure how efficiently locations are using their french fries and how much waste is occurring on a daily basis. Each group has access to the excel spreadsheets that include nightly data on fry sales and use. The mathematical content of this lesson is the idea that efficiency should be measured as a ratio, not a difference. Students ultimately demonstrate this realization by successfully programming an Excel sheet with the efficiency formula that they derived, as shown in Table 1.

Table 1
Sample Spreadsheet from the Fry Efficiency Lesson

Measurement	Day 1	Day 2	Day 3	Day 4
Small fries sold	98	101	67	76
Med. fries sold	145	87	88	143
Large fries sold	123	96	96	58
Cartons used	4	4	3	2
Bags used	2	1	2	5
Weight of bag	2.3	3.1	1.4	0.23
Fry Efficiency				

However, the pathway to demonstrating this understanding begins with students working in groups of four to brainstorm the various factors that affect the efficiency of business operations in the context of french fry usage at an Arby's franchise. With this population of students, we have found that open-ended lessons may be perceived as intimidating. However, the authenticity of the scenario provides a hook to start conversations, allowing students to make some progress without being told the answers. Furthermore, many instructors assign group roles to each student in the style of Process Oriented Guided Inquiry Learning (POGIL), an active-learning methodology that has been applied in fields such as mathematics, chemistry, and nursing (Hanson, 2006; Moog, 2014; Bénéteau et al., 2017; Roller, 2013). This measure helps focus students on a particular responsibility, such as note-taker, spokesperson, or time manager, which adds some structure to an inquiry-based lesson that may otherwise come across as intimidating. By completing the Fry Efficiency lesson, students develop a working understanding of efficiency in the context of running a business and demonstrate mastery of the underlying mathematics of ratios by correctly programming an Excel spreadsheet.

Assessment

In order to teach mathematics in the language of the partner disciplines, we must welcome students to demonstrate mastery in that language as well. In the Fry Efficiency lesson, students demonstrate mastery in formulating equations by correctly programming an Excel sheet. Later in the course sequence, students might demonstrate mastery of the geometric sum formula by correctly computing the future value of an annuity in a grant proposal report (proposed by colleagues in social work). Similarly, students demonstrate mastery of linear equations by correctly depreciating the value of a business vehicle over ten years. Somewhat surprisingly, we have found that students from one discipline are generally motivated to work problems written for the other disciplines as well. It appears that the mere presence of an authentic application of the mathematics does most of the motivational work, while any connection to a student's particular discipline is viewed as a secondary benefit.

We use a variety of assignment types to help us assess content mastery in the various application domains of our partner disciplines. Excel is used in many lessons and assignments, generally in tandem with data sets drawn from applications in accounting, social justice, and medicine. Written reports and oral presentations are both used in assessment, with particular attention to budget projections and funding proposals.

Our grading philosophy mirrors that of the humanities: revision, iteration, and holistic grading. Just as we present mathematics in the language of the partner disciplines, and just as students demonstrate learning in that same language, we aim to assess that learning according to the norms of the partner disciplines. The upshot is a philosophy of grading that is much more akin to professional evaluations, as is appropriate in the partner disciplines. In the context of mathematics education, this grading philosophy is most akin to varieties of mastery- and standards-based grading that have been practiced for decades in K–12 education and have more recently become popular in college mathematics instruction (Stange, 2018).

For example, we give regular review assignments to prompt students to revisit key topics from the past week. In many cases, questions are drawn verbatim from the lessons. The reviews are graded holistically on a scale of **N**eeds improvement, **P**rogressing, and **M**astered. Students are permitted unlimited revisions but must visit office hours if they fail to make progress. By the end of the semester, all review assignments must be mastered in order to pass the class. This policy communicates the instructor's expectation that every assigned question is important and worth doing correctly. One instructor even lays this out concretely to the students by likening their homework to a professional service to be performed (as opposed to a conventional mathematics assignment with points and partial credit).

In our collaborations with faculty in the English composition program, we have learned of the benefits of holistic grading of writing, as discussed in Piercey and Cullen (2017) and recommended by Nilson (2010). Instead of providing comprehensive feedback on each report, we prioritize two or three main areas of improvement. At the beginning of the first semester, these items may include simple formatting and structural improvements. By the midpoint of the course sequence, it is usually possible to begin focusing feedback on key aspects such as tone and audience awareness. Our approach to grading written work represents a different style of mastery grading when compared to the "revise until mastered" policy with review assignments.

Under a "revise until mastered" grading policy for written work, students would be required to revise their entire written reports repeatedly until they obtained mastery, a workload that would risk student burnout. We avoid this risk by helping students focus on achieving a small list of key improvements to their writing. Based on grading trends, we have observed that students generally finish the second semester with demonstrated proficiency in a type of data-driven executive summary that is consistent with the training requested by our colleagues in social work. Moreover, in composing these reports they also demonstrate proficiency in a variety of key Excel skills that are requested by our colleagues in the College of Business. Crucially, we are able to assess mastery of the underlying mathematical concepts through these non-standard assessment types.

Challenges to Portability

As introduced in the previous section, the underlying philosophy of this course sequence is to promote learning of mathematics through inference and discussion. We approach this goal with lessons in discipline-specific scenarios, but these lessons come with a portability challenge when introducing new instructors to QRP.

Discipline-Specific Knowledge

New instructors in the course sequence must thoroughly understand the mathematical application in each scenario, the discipline-specific vocabulary, and any number of related concepts in the discipline that would motivate the scenario. For example, one lesson on linear functions uses the application of depreciating the value of a business vehicle over ten years; another lesson on logarithms involves the pH scale. While the relative simplicity of the underlying mathematics helps matters considerably, new instructors have still encountered difficulties when confronted with the breadth of application domains in the course. Most of these scenarios have undergone heavy revision of exposition, and supplemental instructor versions have been written to help bridge this gap. Moreover, our collaboration with faculty in partner disciplines has broadened into a formal faculty learning community through which new instructors of the QRP course sequence are able to learn discipline-specific knowledge firsthand from faculty in social work, nursing, and business. In Summer 2018, this faculty learning community held a workshop in which new QRP instructors worked alongside the course designers and members of the partner disciplines on lessons such as Fry Efficiency. The faculty learning community then continued to meet for lunch on a biweekly basis throughout the school year to discuss the course and address any instructional concerns.

Teaching Through Excel

We make extensive use of Excel in our lesson design. The first reason for this is that Excel is a convenient intermediate step between arithmetic and algebraic symbolization that has been shown to be effective with the target student population (Piercey & Militzer, 2017). We also want our students to become familiar with Excel and take that familiarity to their respective professions. However, the prominent use of Excel poses a challenge to porting QRP to new instructors. While some instructors may lack experience in the platform, this obstacle is relatively minor in the course sequence since we rely on basic spreadsheet functionality throughout. The more difficult portability challenge comes when trying to teach algebra *through* Excel, as this use of spreadsheets is novel to essentially every new instructor (Piercey, 2017). Without the proper strategies, an Excel lesson can quickly become bogged down by syntax and formatting errors. Instructors must learn how to quickly diagnose and correct these; further, they must eventually learn ways of teaching the students to diagnose and correct their own errors of this kind.

We have found that it is helpful to insist that students write down their proposed Excel code by hand, and then methodically translate this into standard algebra. Not only does this translation clarify the connection between the two forms, but it also greatly helps when showing that different algebraic forms are equivalent. Moreover, highlighting this particular process also helps resolve parenthesis errors in Excel formulas, which are probably the single most common mistake made by students in the course sequence. By setting standards of Excel work early in the class, we find that students quickly become amenable to checking each other's work for syntax errors as well, further promoting active learning in the classroom.

Grading Consistency

The use of written and oral reports in the course sequence is motivated by the goal of assessing student mastery in the language of the partner disciplines. While this has dramatic benefits in including students whose writing or speaking skills are more developed than their symbolic algebraic skills, new instructors are faced with the obstacle of grading written and spoken mathematics, a new challenge for many in the mathematics community. As discussed in the previous section, the written and oral reports are all assigned in the context of a discipline-specific scenario, such as the Fry Efficiency lesson or the Human Trafficking case study. Instructors must therefore bring their understanding of the vocabulary and context of the scenario together with conventional assessment of algebra, all in the context of a written or oral report. Many new instructors have found this type of grading responsibility to be daunting. In Summer 2018, all instructors in the course sequence met and established a grading rubric for written reports (Bishop, Piercey, & Stone, 2020). We also conducted several grading exercises using exemplars from the previous year, comparing and discussing our findings afterwards.

Beyond the assessment of written and oral reports, even assessing the more traditional review assignments also poses a challenge to portability, due to the use of mastery grading instead of conventional points-based grading with partial credit. We find it highly important to use holistic grading policies not only in the written and oral reports but in the weekly review assignments as well. The main reason is that our population of students is generally accustomed to performing at a minimum passing level; many would not attempt to fully master the concepts in a review assignment if 70% completion were acceptable. In our summer instructor meeting, we also conduct grading exercises of exemplar review assignments to help new instructors become accustomed to this style of grading. A discussion of possible grading heuristics is particularly helpful: “would the student benefit from revising,” “could the student explain this to a classmate,” and similar heuristics can be used by the instructor to determine whether a grade of “mastery” is appropriate.

Conclusion

In collaboration with faculty in business, social work, and nursing, we developed a course sequence that teaches fundamental algebra skills through authentic applications of mathematics in these disciplines. The project has resulted in an approach to mathematics instruction that is fundamentally situated in the language and practices of the partner disciplines, yet still achieves the goal of imparting mathematical skills. Professional communication skills are central to the project, as they help students engage with authentic applications of algebra and demonstrate mastery in multiple contexts. We design lessons to promote discussion and inference through real-world problems and assess student learning through written and oral reports in keeping with the practices and standards of our partner disciplines.

This approach to course design has posed several portability challenges for new instructors. First, new instructors to the course sequence must gain familiarity with partner-discipline content in order to guide students through the variety of application domains in the lessons. We have used a faculty learning community to not only help participating mathematics instructors learn directly from the partner-discipline faculty, but also to revise the existing lessons to more and more clearly express discipline-specific content in elementary terms. This ongoing revision process has helped students and instructors alike to engage with the coursework.

Second, the extensive use of Excel in the course sequence necessitates instructional techniques more often found in a computer lab than a typical mathematics course. Instructors new to the course sequence are not always prepared to facilitate Excel-based algebra lessons. We have developed experience-based practices that help instructors anticipate the single most common student error in Excel based lessons: incorrect or missing parentheses. As an added benefit, these practices also tend to encourage students to check the work of their classmates, promoting collegiality and active learning in the classroom.

Third, the variety of assessment types and the use of holistic and mastery grading represent substantial obstacles to adoption by new instructors in the course sequence, as these factors are rather atypical in mathematics courses. As with the challenge of discipline-specific knowledge, the faculty learning community has proven beneficial in obtaining buy-in from new instructors and establishing grading conventions for written work. By interacting with partner-discipline faculty in this community, new instructors gain insight into the grading practices of other disciplines and the value of assessing our students in these new ways. They also gain experience using grading rubrics for written work that were developed by the faculty learning community.

QRP is a living course whose content and instructors are constantly evolving in conversation with our partner disciplines. By adopting the underlying premise that the content of these courses can and should be taught—at least in part—in the languages of business, nursing, and social work, we invite certain challenges but also reap the benefits of our interdisciplinary collaboration. For anyone considering adopting our approach at a different institution, we offer the following advice. Consider holding a fishbowl workshop early on where colleagues from several partner disciplines come together to discuss the technical skills they would like their students to develop (Hofrenning et al., 2020). Our fishbowl workshop not only laid the groundwork for dozens of new lessons but also helped establish buy-in and general good will from members of the partner disciplines who had perhaps not thought much before about the purpose of algebra in their programs. We also recommend establishing some modest incentive for new instructors to participate in a preparatory workshop and ongoing check-in meetings, as these activities were very helpful in supporting our new instructors in their first year of QRP.

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