THE NEED FOR INTERDISCIPLINARY COLLABORATIONS

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ABSTRACT

The challenge faced by developers of collegiate mathematics curricula is to determine—and then provide—the mathematical experiences that are true to the spirit of mathematics yet also relevant to students' futures in other fields. The Curriculum Foundations Project (CF) of MAA/CRAFTY was designed to gather input from partner disciplines through a series of 22 two- to three-day workshops. Each workshop resulted in a report directed to the mathematics community, summarizing the workshop's recommendations and conclusions. One message from the partner disciplines appeared again and again: introductory collegiate mathematics courses should focus on giving students an understanding of fundamental mathematical topics while grounding the discussions in context. The National Consortium for Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnerships (SUMMIT-P) is a group of 16 institutions working to implement the ideals from the CF recommendations. Full participation from partner discipline faculty in this process is a key ingredient in successfully redeveloping introductory mathematics courses in a way that incorporates the contextual needs of other disciplines. The papers in this special issue speak to the work of the SUMMIT-P consortium, focusing on the processes used for successful interdisciplinary collaboration.

KEYWORDS

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

Mathematics plays a critical role in undergraduate education. In fact, employers have emphasized for years that they seek individuals who can think mathematically, reason through problems, and work effectively on interdisciplinary teams (Singapore Ministry of Education, 2018; Steen, 2001). As such, graduates who have meaningful mathematical experiences are better able to face the challenges of careers in both mathematics and other disciplines—including those in non-scientific areas. Additionally, students who are equipped to use technology appropriately, model complex situations, and apply specific mathematics to the work within their chosen fields will be well on their way to a successful career—no matter what their chosen field may be.

This being the case, the real question becomes: How are "meaningful mathematical experiences" defined, and how can (and should) they be measured? Most educators would agree that many mathematics courses are not designed and executed in ways that create such experiences (Lederman, et al., 2013; Walker & Sampson, 2013; Blair, 2006). Students leave these courses with a set of skills they are unable to apply outside of the classroom and for which they do not appreciate the relevance to their future careers. Such experiences do not endear students to the importance of mathematical thinking, creating an urge to finish with required mathematics courses as quickly and painlessly as possible. That attitude often translates to faculty members outside mathematics, with the perception that the mathematics community is not interested in the needs of non-mathematics majors, especially those in introductory courses.

This is a long-standing issue for the mathematics community—and for the discipline of mathematics broadly defined. Educators continue to agree that mathematical thinking is an important skill, as demonstrated by the continuation of mathematics requirements at all academic levels. However, what isn't universally clear is exactly *why* and *in what ways* these mathematical skills are important to the 95% of students in first-year mathematics courses who go on to major in other disciplines. The challenge, therefore, is to determine—and then provide—the mathematical experiences that are true to the spirit of mathematics yet also relevant to students' futures in other fields. The question then is not whether they need mathematics, but what mathematics they need and in what context.

Twenty Years in the Making

In the late 1990s, the Committee on the Undergraduate Program in Mathematics (CUPM) of the Mathematical Association of America (MAA) began discussing the preparation of its next Curriculum Guide (CUPM, 2004, 2015), a document published once each decade since CUPM's formation in 1953. The purpose of the Curriculum Guide is to assist college mathematics departments in the on-going development and improvement of their undergraduate programs. Historically, this document had focused on the traditional mathematics major, with little attention to alternative courses and programs and virtually no mention of mathematics courses for non-mathematics majors. However, it became clear that this important document could no longer ignore the wealth of new programs, courses, and materials resulting from the reform movement in the undergraduate mathematics community. In particular, the dramatic changes being implemented in introductory college mathematics courses, including precalculus, calculus, and differential equations, needed to be studied and directly addressed in the recommendations of the Curriculum Guide.

As a result, in 1999 CUPM initiated a major analysis of the undergraduate mathematics curriculum. As the subcommittee of CUPM concerned with the first two years of college mathematics programs, the Committee on Curriculum Renewal Across the First Two Years (CRAFTY), has a major role in analyzing and formulating recommendations concerning the foundational years in mathematics instruction. Moreover, given the impact of mathematics instruction on the sciences and quantitative social sciences—especially instruction during the first two years—there was a need for significant input from these partner disciplines. Therefore, CRAFTY was charged with gathering this necessary information for the "mathematics intensive" disciplines (e.g., physics, chemistry, and engineering). Thus, the Curriculum Foundations Project was born.

The Curriculum Foundations Project

The Curriculum Foundations Project was designed to gather input from partner disciplines through a series of workshops. The original workshops with colleagues from 17 mathematics-intensive disciplines were held across the country between 1999 and 2001, culminating in a final summary conference in November 2001. A second set of workshops was organized with five additional disciplines (agriculture, arts, economics, meteorology, and social sciences) between 2005 and 2007, creating a combined set of recommendations from representatives of 22 distinct disciplines. These recommendations and the 22 disciplinary reports were published by MAA in two documents: *Curriculum Foundations Project: Voices of the Partner Disciplines* (Ganter & Barker, 2004) and *Partner Discipline Recommendations for Introductory College Mathematics and the Implications for College Algebra* (Ganter & Haver, 2011). The results also contributed significantly to the content of the two most recent Curriculum Guides (CUPM, 2004; 2015).

Each Curriculum Foundations (CF) workshop lasted two to three days and consisted of 20−35 participants, the majority chosen from the partner discipline(s) under consideration, the remainder chosen from mathematics. The workshops were not intended to be discussions between mathematicians and colleagues in the partner disciplines, although this certainly happened informally. Instead, each workshop was organized in a "fishbowl" style that encouraged dialogue among the representatives from the partner disciplines, with mathematicians present only to listen and serve as a resource when questions about the mathematics curriculum arose. A set of guiding questions was used to motivate the conversation and produce responses that could be combined across disciplines. Each workshop resulted in a report directed to the mathematics community, summarizing the workshop's recommendations and conclusions. The reports were written by representatives of the partner disciplines, ensuring accurate reporting of the workshop discussions while also adding credibility to the recommendations.

The host institutions funded most of the workshops. Such financial support indicated the high level of support from university administrations for such interdisciplinary discussions about the mathematics curriculum. Workshop participants from the partner disciplines were extremely grateful—and surprised—to be invited by mathematicians to state their views about the mathematics curriculum. That the opinions of the partner disciplines were considered important and would contribute to national mathematics policy only added to their enthusiasm for the project as well as their interest in continuing conversations with the mathematics community.

In addition to the workshop reports, the CF project resulted in a number of publications that describe the workshops, their outcomes, and related work. These publications include articles in journals of the disciplinary societies as well as the general press. Conversations also continued via panels and invited colloquia at professional meetings, both in mathematics and the partner disciplines.

Recommendations for the Undergraduate Mathematics Curriculum

Whether the workshop focused on physics, engineering, economics, or the arts, the message from the partner disciplines was repeated again and again: introductory collegiate mathematics courses should focus on giving students an appreciation and understanding of fundamental mathematical topics while grounding the discussions in context. The specific topics are not as important as 1) technical confidence; 2) the application of mathematics to a variety of contexts; and 3) the ability to choose appropriate tools for modeling, evaluating, and communicating mathematical results (Ganter & Barker, 2004; Ganter & Haver, 2011). Specifically, the collective CF reports recommend emphasis on the following:

Conceptual Understanding

- Focus on understanding broad concepts and ideas in all mathematics courses during the first two years.
- Emphasize development of precise, logical thinking. Require students to reason deductively from a set of assumptions to a valid conclusion.
- Present formal proofs only when they enhance understanding. Use informal arguments and well-chosen examples to illustrate mathematical structure.

Problem Solving Skills

- Develop the fundamental computational skills the partner disciplines require, but emphasize integrative skills: the ability to apply a variety of approaches to single problems, to apply familiar techniques in novel settings, and to devise multi-stage approaches in complex situations.

Mathematical Modeling

- Expect students to create, solve, and interpret mathematical models.
- Provide opportunities for students to describe their results in several ways: analytically, graphically, numerically, and verbally.
- Use models from the partner disciplines: students need to see mathematics in context.

Communication Skills

- Incorporate development of reading, writing, speaking, and listening skills into courses.
- Require students to explain mathematical concepts and logical arguments in words.
- Require students to explain the meaning—the hows and whys—of their results.

Interdisciplinary Priorities throughout Content and Courses

- Strive for depth over breadth.

- Offer non-calculus-based descriptive statistics and data analysis.
- Develop curricular materials within calculus and linear algebra that are appropriate for the needs of partner disciplines.
- Replace traditional college algebra courses with courses stressing problem solving, mathematical modeling, descriptive statistics, and applications in the appropriate technical areas.
- Pay attention to units, scaling, and two- and three-dimensions (Ganter & Barker, 2004).

Because the CF recommendations were compiled from the collective input of 22 disciplinary working groups, they are broadly defined and encompass a wide variety of perspectives. Therefore, effective implementation of the recommendations requires continuous conversations with the partner discipline faculty, allowing them to collaborate with mathematics faculty in the development of curricula that include disciplinary context. For example, the CF recommendation that students create, solve, and interpret mathematical models as applied to chemistry would involve utilizing solutions that are highly visual; i.e., students must be able to visualize structures and atomic and molecular orbitals in three dimensions (Ganter & Barker, 2004, p. 29). The same recommendation applied to civil engineering might take a more analytical or numerical path, utilizing technology-based mathematical techniques to arrive at a solution and determine its limitations (Ganter & Barker, 2004, pp. 58 – 59).

SUMMIT-P: Promoting Collaborations across Disciplines

While the effective implementation of the CF recommendations requires collaboration across a large and diverse set of disciplines that are making ever greater use of mathematics, no mathematics department can offer a different set of mathematics courses for each partner discipline. Therefore, it is critical to rethink and revise the most common introductory mathematics courses. Since the broad categories of conceptual understanding, problem solving, mathematical modeling, and communication cut across the recommendations from all partner disciplines, introductory mathematics courses should be redeveloped in ways that incorporate these universal needs.

The Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnerships consortium (SUMMIT-P) is a nationally-distributed group of 16 institutions[1] working to implement the ideals from the CF recommendations through cooperation with a variety of partner disciplines. Full participation from partner discipline faculty in this process is a key ingredient in successfully redeveloping introductory mathematics courses in a way that incorporates the contextual needs of other disciplines. As such, the consortium's first task was to find ways to best engage colleagues in the partner disciplines. Initial conversations at SUMMIT-P meetings led to activities that experimented with a variety of mechanisms for that purpose.

[1] At the time they were written, the papers in this special issue describe the work of multidisciplinary curriculum development teams at nine institutions, supported by a Project Management Team involving four additional institutions. The projects at the nine implementation sites are briefly described in *Curricular Change in Institutional Context: A Profile of the SUMMIT-P Institutions*. Subsequent to the writing of the papers in this issue, three other institutions—Embry-Riddle Aeronautical University, University of Tennessee at Knoxville, and Humboldt State University—have joined the SUMMIT-P project, bringing the number of multidisciplinary curriculum development teams to twelve.

Specifically, because this collaborative approach for curriculum development is being implemented at a variety of institutions, each institution has 1) used locally appropriate strategies, 2) engaged faculty from locally-selected partner disciplines, and 3) focused on mathematics courses selected by that institution. However, each SUMMIT-P institution has undertaken the following processes:

- Faculty have studied the CF recommendations and the relevant disciplinary reports.
- Opportunities have been provided for partner discipline faculty to describe to mathematics faculty which of these CF recommendations are most important to their students, often through "fish bowl" activities.
- Partner discipline faculty have developed wish lists of mathematical topics and experiences their students need, and mathematics courses are being changed in response to these lists.
- Faculty have participated in local professional development experiences (through seminars and learning communities) and SUMMIT-P professional development (through webinars, poster presentations, panel discussions, and the development of this special issue).
- Courses are being developed, piloted, and refined in a collaborative fashion involving faculty and students from mathematics and partner disciplines.
- Mathematics and partner discipline faculty have visited courses offered outside of their departments.
- Faculty have participated in SUMMIT-P "course clusters" that frequently bring together institutions that are working on similar mathematics courses to discuss implementation strategies and outcomes.
- Teams from other SUMMIT-P institutions as well as project leadership and evaluation personnel have visited each SUMMIT-P institution to 1) attend classes, 2) interact with faculty and administrators, and 3) talk with students; these site visits are organized using a protocol designed to help the host institution plan for and conduct the visit in a way that engages the broad college community.
- In turn, mathematics and partner discipline faculty at each institution have visited other SUMMIT-P institutions.

JMSCE Special Issue Articles

The papers in this special issue speak to the work of the SUMMIT-P consortium as the project reaches the four-year mark, focusing on the processes used for successful interdisciplinary collaboration (as opposed to the curricular changes that have and will be implemented). Indeed, the SUMMIT-P participants believe that these processes constitute the most important contribution of the SUMMIT-P work to the national effort called for by CF and the CUPM curriculum guides.

Some of the processes deployed by members of the consortium are described in this issue as follows:

Fishbowl Discussions: Promoting Collaboration between Mathematics and Partner Disciplines describes how "fishbowl" discussions were used to enable mathematics faculty to understand the perspective of faculty in partner disciplines. It also describes how "wish lists" were developed to enunciate the needs of students studying topics in the partner disciplines.

Using Site Visits to Strengthen Collaboration describes the power of site visits for strengthening the collaboration among faculty from different disciplines. Site visits allow curriculum developers and implementers to narrow the focus of their efforts, contribute to community building, support cross-pollination of ideas, and provide dedicated time to reflect on the ongoing work.

Structured Engagement for a Multi-Institutional Collaborative to Tackle Challenges and Share Best Practices highlights two protocols that provide a structured format to give feedback to partners who are seeking advice on a challenge they are experiencing and to enable partners to share their success stories. While collaboration among different institutions and different disciplines is extremely powerful, it also can be challenging; formal protocols can be a useful tool for supporting this collaboration.

Paradigms for Creating Activities that Integrate Mathematics and Science Topics describes how mathematics and partner discipline faculty from three universities developed integrated activities that illustrate real-world applications of the mathematics topics being studied in Precalculus and Calculus. These activities address the statement in the CF recommendations that undergraduates need to see connections and applications of mathematics across and among their quantitative reasoning courses.

Using a Faculty Learning Community to Promote Interdisciplinary Course Reform describes the development and implementation of a faculty learning community that enabled faculty from mathematics, nursing, social work, and business at one institution to redesign mathematics content and vertically integrate mathematics into the partner discipline programs. Intentional efforts are required to support collaboration among disciplines; different SUMMIT-P institutions used different mechanisms and this paper reports on one successful approach.

The Roles and Benefits of Using Undergraduate Student Leaders to Support the Work of SUMMIT-P provides examples of how undergraduate peer leaders at different universities provided support in creating and implementing interdisciplinary lessons to enhance lower division mathematics courses. The engagement of the peer leaders is beneficial to faculty, to students in the target courses, and to the undergraduate peer leaders as well.

The Process and a Pitfall in Developing Biology and Chemistry Problems for Mathematics Courses explains the process used for developing applied problems from biology and chemistry for use in a Differential Calculus course. It includes a discussion of the role that peer students played but also deals with how these problems will be used by instructors who did not participate in their development.

Counting on Collaboration: A Triangular Approach in the Educator Preparation Program for Teachers of Mathematics describes collaboration among college mathematics faculty, education faculty, and teachers and administrators in a local school district. One goal was to ensure that teachers of pre-service teachers incorporate mathematical learning and teaching through manipulatives in their pedagogy courses.

Integrative and Contextual Learning in College Algebra: An Interdisciplinary Collaboration with Economics reports on how faculty at one community college used the CF reports to initiate discussion between economics and mathematics faculty members. Based upon these discussions and a review of the literature, student activities with real world applications are being developed to enhance the college algebra course and plans were made for professional development for all instructors.

Promoting Partnership, Cultivating Colleagueship: A SUMMIT-P Project at Norfolk State University describes a strong partnership developing at one university between mathematics and engineering faculty. It also reports on how a SUMMIT-P site visit played a crucial role in providing focus to their collaborative work.

Designing a Student Exchange Program: Facilitating Interdisciplinary, Mathematics-focused Collaboration among College Students shares the details of a student exchange program providing interdisciplinary experiences for students majoring in mathematics, statistics, or social sciences. The paper describes how the program is proving to be valuable not only for the participants but also students in statistics classes and both statistics and social science faculty.

From Creative Idea to Implementation: Borrowing Practices and Problems from Social Science Disciplines discusses the challenges to developing a mathematics course in collaboration with partner discipline faculty, with particular attention to portability. As faculty beyond the original collaborators and developers teach the course, attention needs to be paid to instructor familiarity with applications, varieties of assessment styles, and grading consistency.

Good Teachers Borrow, Great Teachers Steal: A Case Study in Borrowing for a Teaching Project describes how a set of courses at one university is being developed based on continual borrowing and stealing of ideas. Borrowing takes place from textbooks and CF reports as well as by joining the SUMMIT-P consortium, collaborating with faculty from partner disciplines, and visiting other sites and hosting site visits.

Evaluating a Large-Scale Multi-Institution Project; Challenges Faced and Lessons Learned reports on the on-going evaluation of SUMMIT-P and describes how the evaluation provides a birds-eye view of the work that those entrenched in the project are not able to see. It also discusses lessons being learned as the evaluation continues that could be valuable to others involved in multi-site evaluations.

Curricular Change in Institutional Context: A Profile of the SUMMIT-P Institutions provides a brief description of the context and work being conducted at each of the SUMMIT-P institutions. The authors invite faculty at other institutions interested in conducting similar work to peruse the descriptions and find familiar institutions, geography, curriculum goals, and mathematical topics and then to reach out to these institutions for support and further collaboration. This paper concludes with a "getting started" check-list.

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