Time for (Research on) Change in Mathematics Departments

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This research commentary argues for more research that attends to the processes of organizational change in mathematics departments. It outlines both the ways that research on organizational change can benefit scholarship in mathematics departments, and how mathematics education researchers are needed to develop theories of change that are contextualized to the teaching and learning of undergraduate mathematics. This commentary closes with a research agenda for moving this emergent field of study forward. This agenda involves applying change theories to historical, ongoing, and new change projects in mathematics departments, while simultaneously attending to issues of equity and social justice.

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Research in undergraduate mathematics education (RUME) has long embraced the complementary goals of explicating fundamental processes of – and improving – the learning and teaching of mathematics. This often means examining change, but the objects of inquiry into what is changing have varied over time. Much of RUME has focused on learners, including conceptual or cognitive change, change in affect, change in discourse, and change in participation in classroom and mathematical practices. More recently, RUME is attending to undergraduate teachers to examine change in beliefs, knowledge, discourses, instructional approaches, assessment practices, and use of resources. A third focus of change has been on the dynamic nature of theory, especially as it relates to cultural shifts and the context in which theory has been developed (Inglis & Foster, 2018; Rasmussen & Wawro, 2017; Winsløw et al., 2018). Overall though, with a few exceptions (e.g., Rämö et al., 2019), largely missing is a focus on change in mathematics departments. In this *Research Commentary*, we call for research that focuses more emphatically on the processes and reasons by which organizational change in mathematics departments is initiated, implemented, and sustained. Such work, we argue, will necessarily build on, and leverage, the rich body of research focused on learners, teachers, and theory.

Research on change in mathematics departments is needed as departments take the growing and sustained calls for improvement in mathematics and science learning and teaching more and more seriously. Examples of such calls include the President's Council of Advisors on Science and Technology (PCAST) in the United States (PCAST, 2012) and the Rocard et al. (2007) report in Europe. While such politically and socio-economically motivated calls for improvements are not new, what is new is the extent to which mathematics departments are taking responsibility and ownership for improving the learning and teaching of undergraduate mathematics. For instance, in the US (CBMS 2016; MAA 2017; Saxe and Braddy 2015) and in the UK (London Mathematical Society, 1995; IMA, 1999; Hawkes & Savage, 2000; ACME, 2011; British Academy, 2012; Croft & Lawson, 2017) professional societies have been actively encouraging mathematics departments to increase their use of student-centered instructional strategies to address the learning needs of increasingly diverse student cohorts, strengthen interest and persistence in mathematics and science, and address systemic inequities. In addition, mathematics departments are also joining efforts for changing school mathematics. For instance, the Promoting Inquiry in Mathematics and Science Education Across Europe (PRIMAS) project brought together 14 universities from 12 European countries to further promote the uptake of inquiry-based approaches in school mathematics and science (see http://www.primas-project.eu).

One direction that these international change efforts have taken is towards inquiry-based mathematics education (IBME) (Artigue & Blomhøj 2013; Laursen & Rasmussen 2019). Laursen and Rasmussen (2019) define inquiry in terms of four aspirational pillars. Two of these pillars emphasize what students do (students engage with coherent and meaningful mathematical tasks deeply and students process mathematical ideas collaboratively) and two emphasize what teachers do (teachers inquire into student thinking and teachers foster equity in their design and facilitation choices). Realizing such a vision requires a systems approach that positions the mathematics department as the appropriate object of inquiry. What is at stake here is core to the mission of RUME – what mathematics is taught, what mathematics is learned, and the mathematical experiences of students. For example, ongoing work in the mathematics department at the University of Helsinki is radically transforming the nature of students' mathematical experiences (and hence what they learn) by transforming departmental culture as a result of introducing a version of IBME known as the Extreme Apprenticeship approach (Rämö et al., 2019). In considering transformation in departmental culture, a theoretical approach is adapted from organizational science that defines culture as "a historical and evolving set of structures and symbols and the resulting power relationships between people" (Reinholz & Apkarian, 2018, p. 3).

Research that examines the uptake of change efforts such as IBME needs to go well beyond the walls of the classroom and consider departmental and institutional culture, norms and values, reward systems, and the ecosystem in which departments operate. We refer to taking such a systems approach to investigating departmental change as *change research*. Research on systemic change has traditionally been grounded in the field of organizational change, which investigates the nature of organizations and how they change. These changes may be unplanned, in response to societal forces, or planned and at the hands of change agents who wish to upend the status quo. Over the past few decades, scholars of higher education (e.g., Kezar, 2014) and STEM organizational change (Borrego & Henderson, 2014; Henderson et al., 2011) have made great strides to apply these theories to the improvement of undergraduate STEM studies generally. Still needed, however, is greater attention to the specific elements of change processes within mathematics departments.

Drawing on what is already known about change in STEM departments, mathematics educators can harness existing theories in order to increase the likelihood that their work is taken up by mathematics departments. Simultaneously, the skills of the mathematics education community are required to contextualize change theories to mathematics education contexts, because mathematics educators have expertise regarding the nature of mathematics, mathematics departments, and societal narratives about mathematics. We posit that, akin to how (mathematics) education research provides a foundation for RUME, organizational change research can also contribute to understanding change in mathematics departments.

In what follows, we outline why an academic department is an important unit for change. We then explore possible connections between RUME and change research in three areas: using change research to support RUME; how RUME can support change research; and, a preliminary research agenda for the study of systemic change in mathematics departments. This commentary is a call to action, one that we hope will serve as a first step towards networking two historically disparate fields, RUME and change research.

Academic departments as a site for change

Traditionally, instructional change has focused primarily on individuals, through the dissemination of new teaching practices and curricula. In general, dissemination approaches tend to have a modest impact at best (e.g., Henderson et al., 2010; Stains et al., 2018) because they ignore the deeply ingrained institutional practices and discourses within which teaching and learning are embedded (Kezar, 2014). For example, when one considers undergraduate mathematics teaching in the US, lecture is still the predominant form of instruction (Laursen et al., 2019). Despite relatively modest uptake, a number of innovative new pedagogies, curricula, and professional development methods have been created, and are used in some departments (Laursen et al., 2019). We argue that, with a more concerted effort for the adoption of practices and changing of the educational system, the uptake could be greatly enhanced.

One of the issues with a dissemination model is that when instructors do adopt new teaching practices they may use them ineffectively (Andrews et al., 2011) or discontinue their use altogether (Henderson et al., 2012). Even faculty who are well-equipped to use new strategies effectively may choose not to do so, due to conflicting institutional pressures (such as a departmental culture that exerts the pressure to “publish or perish” and the role of student evaluations in retention and promotion). In such situations, what may be needed is a transformation of institutional policies and discourses to support learning and teaching. Challenging dominant discourses often involves exploring clashes of values that may lie at the heart of institutional resistance to change (inertia).

In this sense, academic departments can be considered as a critical site for change (American Association of Colleges & Universities, 2014). Departments have a relatively consistent internal culture, as evidenced by their policies (e.g., teaching loads and committee structures), norms, disciplinary content, and faculty interactions. Moreover, departments may have considerable latitude in how they design their courses and socialize students (Quardokus & Henderson, 2015). Thus, by situating change within a department, it is possible to make structural changes and create internal supports that empower faculty to create effective learning and teaching environments. In contrast, if the stabilizing function of a department's culture is ignored, a change effort is much less likely to have sustained impact (Reinholz, Ngai, et al., 2019). Moreover, within the context of a university, a department has a certain level of coherence and stature that may support it to influence institutional policies more broadly. Where departments may function differently – for example, in the context of highly centralized higher education systems in some European countries where universities and their departments fall under the jurisdiction of central government departments, such as Ministries of Education (Paradeise et al., 2009) – it may be appropriate to choose another functional unit (either smaller or larger) as a focus for change.

Nonetheless, research suggests that STEM cannot be treated as a monolith, but rather, that change within departments of each of the STEM disciplines is different (Reinholz, Matz, et al., 2019). This means that what is known generally about change in science and engineering disciplines may not directly translate to mathematics departments. For example, mathematics departments make extensive use of assisting teaching staff, which in the US includes visiting instructors, graduate teaching assistants, and part-time and full-time adjunct instructors. These instructors have a unique role, which may require different coordination structures than in other sciences. For this reason, research situated specifically within mathematics departments is required to understand the unique aspects of change within mathematics departments, as opposed to other academic departments in higher education. Recent work in this area is of different types. We cite three examples: one from a project that involves mathematics departments in a cross-institutional, national initiative in the US; one that concerns the emergence of mathematics learning support centres, not necessarily within mathematics departments and in a range of different countries; and, one that concerns the development and extensive use of a particular theory in mathematics education research that is becoming the vehicle for designing, implementing and evaluating change in mathematics departments.

A first example is the Student Engagement in Mathematics through an Institutional Network for Active Learning (SEMINAL) project in the US, a five-year national study of mathematics departments which are in the process of changing the way precalculus and calculus is taught and learned (see aplu.org/seminal). Specifically, fifteen mathematics departments developed their own change strategies, ones that fit their local context, to infuse active learning into the introductory mathematics courses required of all science and mathematics majors, to build a community of practice among faculty delivering these courses, and shift department norms and culture in ways that further support and ultimately sustain the improvement efforts. The primary research focus is on this question: What conditions, strategies, interventions and actions at the departmental and classroom levels contribute to the initiation, implementation, and institutional sustainability of active learning in the undergraduate calculus sequence across varied institutions? In addressing this question, the research team is conducting a two-year longitudinal study that takes a systems perspective and networks change agents within the mathematics departments. The ultimate goal is to build theory about effective strategies to initiate and sustain change in these departments.

A second example is the body of research focusing on Mathematics Learning Centers (MLCs) established at universities (e.g., in the UK, Australia, Ireland) since the 1990s (Matthews et al., 2013). Mathematics support in universities has evolved from small-scale initiatives set up by university mathematics teaching and communication enthusiasts to mainstream, institutional, and in some cases cross-institutional efforts. Thus, while MLCs may not necessarily reside within a mathematics department, they are an organizational unit that plays an important role in the teaching and learning missions of mathematics departments, and thus are apt to be studied from organizational perspectives. Research on MLCs is often both quantitative (e.g., focusing on student use) and qualitative (e.g., focusing on student priorities for use and impact statements). At an organizational level, this research often also focuses on the impact that such a center may have on the teaching and learning of mathematics that takes place for the experiences of staff, students and for the institution itself (Matthews et al., 2013).

Finally, our third example is the Anthropological Theory of the Didactic (ATD), which focuses on the interface of teaching, learning, and organizational structures (Chevallard, 2006). Its tools aspire to embed the study of teaching and learning of mathematics firmly into the institutional structures in which this teaching and learning takes place. ATD focuses on the *ecology* of mathematical and didactic praxeologies, which are defined as "the conditions that enable or favor the development of [a certain] praxeology in the institution, and the constraints that tend to impede that development." (Winsløw et al., 2014, p. 97). Chevallard's *Study and Research Paths* (SRP) construct is intended exactly as a tool for studying the ecology of didactic organizations and work on this is starting to grow (e.g., Barquero et al., 2013). This type of work is necessary to situate individual- and classroom-based processes within larger departmental contexts.

What can change research do for mathematics departments?

Translating what is known in the mathematics education research community to changes in instructional practices is not straightforward (Sztajn et al., 2017). What is clear from the secondary school literature, however, is that professional development must be sustained to have a lasting impact; one-shot workshops have limited efficacy. However, how can a department create deeper learning opportunities for its faculty? In addition to drawing upon research on teaching and learning, this requires attention to structural issues: How will the professional development be funded? What incentives are available? How does a department build a community of practice around teaching and learning? How can such a program be sustained? Answering these types of questions requires careful attention to context – both departmental, and institutional – and theoretical frameworks from change research can support the investigation into such questions. Moreover, understandably, teachers at all levels resist simply being told what to do. Mathematics education research goes some way to address this concern. For example, Nardi (2008; 2015; 2016) identifies five characteristics of productive interactions between researchers in mathematics education and research mathematicians: "*collaborative* (namely, it engages mathematicians and mathematics educators in as many phases of the research as possible), *mathematically focussed* (e.g., on particular topics in the university syllabus), *context-specific* (e.g., to the learning and teaching environments of the institutions within which the research takes place), *non-prescriptive* (its primary aim is not to offer quick-fix solutions to long-standing pedagogical problems) and *non-deficit* (it stays clear of apportioning blame, for instance, to student lack of mathematical ability or lecturer lack of pedagogical sensitivity or skill)" (Nardi, 2015, p. 213). The synergy between the communities working towards change needs to be co-constructed and ownership of change initiatives needs to be shared.

Change research can also help address the relationship between mathematics and society. Because most professional mathematicians work within academic departments, the perceptions that exist about mathematics departments can either help reproduce or problematize narratives that create hierarchies about who can be successful in mathematics, both in relation to race (Shah, 2017) and gender (Solomon et al., 2011). Efforts to improve equity at a classroom level (e.g., Reinholz & Shah, 2018) can help address such narratives and create a more equitable learning environment. However, if these micro-level efforts are not coupled with a larger systemic change process, they are less likely to have transformative impact on these narratives and their pervasiveness in school mathematics. Given that universities often serve as role models for school mathematics (e.g., as in the PRIMAS project), mathematics departments are also needed to help challenge such narratives, for instance, through new institutional policies and progressive hiring practices.

Lastly, change research can inform the design and planning of RUME projects. Given that small-scale, one-off interventions and dissemination approaches to improving learning and teaching are largely ineffective (Henderson et al., 2011), careful thought is required from the outset to help translate theory into practice. For this reason, it may be imperative for the RUME community to consider how other stakeholders – including administrators, students, community members – might be involved in the research process in a way that leads to greater uptake and practical impact. This could potentially open up a variety of new and productive research directions within RUME. Although change research will not necessarily influence all RUME projects, we argue that there are many that could benefit from adopting such a perspective.

What can mathematics education do for change research?

The RUME community also has much to contribute to change research. When it comes to understanding the organizations relevant to mathematics teaching and learning, the RUME community has deep expertise. With an understanding of academia in general, and mathematics departments in particular, RUME scholars can build on what is already known more generally in organizational change, to situate organizational theories to the specific context of mathematics departments. In addition to serving the needs of the RUME community, this could also contribute to theories of organizational culture more broadly. For example, theories developed in the context of RUME would also be relevant to other organizations where workers are highly educated and have considerable autonomy.

In addition to conceptualizing the culture of mathematics departments, RUME scholars can contribute to how those cultures change. Ideas such as academic freedom, the specific parlance of mathematics and discourses on the teaching and learning of mathematics, or the very diffuse power structures in academia are everyday concepts for RUME researchers; they are not well-studied in traditional change research, which historically has been conducted mostly in business and nonprofit organizational settings. Yet, these ideas must be accounted for in order to understand how mathematics departments change. For example, given that the locus of power in an academic department is much more diffuse than in a corporation, top-down incentives and restructuring strategies that are available to businesses will not work in the same way within academia. Still, there are many relevant models of change that have already been developed (e.g., Kezar, 2014; Krücken, 2014), but more work is required to understand how to modify them for systemic organizational change. The goal would be to generate useful and applicable models that are simple to understand and that work in academic contexts. These models could later be translated back to other settings.

The RUME community can also contribute to educating others about how change happens. For instance, if researchers are working in partnership with a university department to implement changes, they must understand the resources the administration might draw upon to think about change. More broadly, this area of research can be considered "change education", which focuses on how to teach people about change. This may include negotiating what colleagues in a mathematics department may expect from educational research (theory and practice). For example, Nardi (2008) found that the mathematics education researchers who worked closely with colleagues in mathematics departments experienced, very frequently, the need to challenge views on how humans learn and how these views impact how we teach. Individual views on these are challenged and often change in the course of collaborative research, but, so far, this has been mostly at the individual participant level, not at the departmental level and beyond. In order for educational improvement efforts to be most effective, they need to include some aspect about how to make change happen. Because change in mathematics education is different from other types of change, mathematics educators need to contribute to this understanding.

Finally, mathematics education researchers are experts in many forms of learning. While organizational change is the dominant field focused on how systems evolve, there are still many relevant theories that the RUME community can contribute. By drawing these connections between the learning of individuals and systems, both fields may develop more robust understandings of learning and change.

A Research Agenda for Change in Mathematics Departments

Our research agenda proposition for **change in mathematics departments** consists of four critical areas. We argue that change research needs to focus on (1) analyzing historical efforts, (2) studying ongoing efforts, and (3) creating new efforts. Lastly, we argue for the need to focus on (4) issues of equity and social justice.

Historical efforts. Mathematics educators have been working towards educational change for decades (e.g., the Calculus Reforms in the US; Schoenfeld, 1995). However, such efforts have rarely been studied from a STEM educational change perspective. Given recent syntheses of change theory for STEM higher education (e.g., Kezar, 2014), there is a valuable opportunity to apply what is known and contextualize it to mathematics departments. Existing syntheses can speak to STEM educational change broadly, but they do not cover specifics of mathematics departments and their teaching and learning context. Using historical efforts as a starting place for contextualizing change theories to mathematics will support a more productive use of change theory for new and existing change projects. For this reason, the RUME community needs to work to contextualize more traditional theories of change and apply them to the context of mathematics departments.

Existing efforts. Research on change in mathematics departments is an emerging area of study, as evidenced in the recent special issues edited by Bressoud & Zorn (2018) and Rasmussen et al. (2019). At the same time, many of these projects are driven by grassroots efforts from department chairs or other change agents who may not be well-versed in theories and models about how change works. The research community needs to become involved, study, and ultimately drive this process forward. Applying theories of change to understand and enhance ongoing efforts will also further the first goal of developing more contextualized theories of change in RUME.

New efforts. Given the increasing economic and societal pressures we outlined earlier, there is an urgent need to improve undergraduate mathematics education. The RUME community may lead these changes or may merely follow them. We wish to make a case for the former. Beyond studying existing change efforts, the RUME community can provide guidance to change agents to inform studies from the offset. Because the community has productive entry and access points to change efforts taking place in undergraduate mathematics education, it is well-positioned to play this specialist role, particularly as compared to non-specialist researchers in educational change. By developing well-grounded studies from the outset, change efforts can become an important tool for developing theory through new empirical studies. This type of approach is consistent with the methods of Design-Based Implementation Research (DBIR; Penuel et al., 2011) and Improvement Science (Lewis, 2015), both of which aim to develop richly contextualized theories as a part of a change process.

Attend to issues of equity and social justice. Mathematics education is increasingly embracing a research agenda that attends to issues of equity and social justice (e.g., Gutierrez, 2002; Laursen & Rasmussen, 2019; Giraldo, 2018). Yet, a long history of reform efforts in primary and secondary education shows that change can be highly political, as in the so-called "math wars" (Schoenfeld, 2004) or reforms associated with the Common Core State Standards (Wagner, 2016). Similar issues exist in higher education, whether through politically-motivated criticisms of mathematics education scholars (Math Ed Collective, 2018) or debate around the use of diversity statements for job applications (Thompson, 2019). Given the focus on change to support equity in mathematics, this is an apt moment to synthesize what is known about equity in mathematics education with scholarship on educational change in order to create theories of change for equity. This would also be of benefit to the educational change community broadly, itself grappling with how to best attend to equity in its scholarship (i.e.. Apkarian et al., 2019).

Concluding Remarks

Organizational change is a highly complex sociopolitical process, which requires attention to the interaction and influence between a mathematics department and the university system. These larger systemic forces play an important role in change of learning and teaching environments, and consequently, cannot be ignored. For example, in the UK the national research and teaching assessment exercises have generated a dominance of top-down approaches (Kinchin & Winstone, 2017). For a university to rank highly, innovation in pedagogy must be shown across its departments. This has meant that departments can be somewhat reluctant towards embracing change, given the risk, challenge, and costs of implementing new strategies. As a result, innovations are often imposed on departments. This is proving to be a double-edged knife for RUME work in mathematics departments. One impact of this external pressure is that departments may be more willing to uptake reforms. At the same time, it makes it more difficult for departments to engage with (or even enact) the possibility of long-lasting implementation of said reforms, which requires ongoing commitment. In this way, organizational change can become a game of chasing silver bullets, which results in moving from one innovation to the next, rather than investing the time needed to make a single innovation last meaningfully. In the US, professional organizations have put out supporting statements in favor of inquiry-based learning (e.g., CBMS, 2016), which encourage mathematics departments to change without a top-down mandate *requiring* them to change. In both examples, we see different organizations outside of the university, and potentially their different impact in different contexts.

Building on the considerable progress that has been made in understanding teaching and learning, there is an urgent need for a systems approach that can simultaneously account for this complex landscape of change. RUME has a long history of drawing from other fields to achieve its goals. Just as general theories of teaching and learning can provide the basis for contextualized theories of learning and teaching in mathematics education, general theories of organizational change can provide the necessary but insufficient foundation for understanding mathematics departmental change. As RUME scholars develop these deeper, more contextualized theories, the capacity of the community to study, enact, and sustain change will be enhanced. At this moment in time, there are changes within mathematics education that are happening and that need to happen. There is an important role for the RUME community: its scholarship can equip those who would initiate, shape, and implement these changes.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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