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Classroom environments in which students are provided opportunities to engage in mathematical investigation, communication, and group problem-solving, while also receiving feedback on their work from both experts and peers, have a positive effect on learning. Teaching techniques that support these activities are called active learning methods. Because there is not a unique definition of active learning, either in popular use or in the research literature, we use the phrase *active learning* to refer to classroom practices that engage students in activities, such as reading, writing, discussion, or problem solving, that promote higher-order thinking. Recent years have seen an increased awareness of the critical role of active learning techniques, a refined understanding of how they can be implemented effectively, and a substantial increase in their implementations in post-secondary mathematics courses. A wealth of research has provided clear evidence that active learning results in better student performance and retention than more traditional, passive forms of instruction alone. Post-secondary faculty and P-12 educators have successfully used active learning methods in a diverse set of institutions and across a broad range of teaching environments. These methods have been shown to strengthen student learning and achievement in mathematics, to foster students' confidence in their ability to do mathematics, and to increase the diversity of the mathematical community. In recognition of this, ***we call on institutions of higher education, mathematics departments and the mathematics faculty, public policy-makers, and funding agencies to invest time and resources to ensure that effective active learning is incorporated into post-secondary mathematics classrooms.*** We further call on professional societies and funding agencies to continue their support of training and resources for the use of active learning. We believe that using active learning methods in a way that builds on the extensive previous and ongoing work to modernize mathematics curriculum and pedagogy will lead to richer and more meaningful mathematical experiences for both students and teachers.

Support for active learning in the mathematical sciences is found in many studies, reports, and publications over several decades, for example the Mathematical Association of America *Curriculum Guides*, the American Statistical Association *Curriculum Guidelines for Undergraduate Programs in the Statistical Sciences*, the American Mathematical Association of Two-Year Colleges reports *Crossroads* and *Beyond Crossroads*, the Society for Industrial and Applied Mathematics *Modeling Across the Curriculum* and *GAIMME* reports, the National Council of Teachers of Mathematics report *Principles to Actions*, the American Mathematical Society report *Towards Excellence*, and others. Many of these are synthesized in the 2015 MAA report *A Common Vision for Undergraduate Mathematical Sciences Programs in 2025*. A clear case for active learning across STEM disciplines is

made in the landmark study *Active learning increases student performance in science, engineering, and mathematics*, by Freeman, et al., published in the 2014 Proceedings of the National Academy of Sciences. This meta-analysis of 225 studies comparing active learning to traditional lecture alone in undergraduate STEM courses found that active learning significantly increased students' assessment performance and decreased course failure rates, and further that "active learning confers disproportionate benefits for STEM students from disadvantaged backgrounds and for female students in male-dominated fields."

Active learning methods are one of many factors that contribute to student learning. The influential 2013 National Research Council report *The Mathematical Sciences in 2025* recommends a broad re-examination of both content in and traditional methods for teaching post-secondary mathematics. Due to the scale and importance of this undertaking, the authors of the NRC report explicitly call for "a community-wide effort," stating that "the professional societies should work cooperatively to spark this." Through this call for the use of active learning we are taking one step toward addressing the recommendation in the NRC report and meeting our goal of offering an excellent post-secondary mathematics education to every student.

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Background to “Active Learning in Post-Secondary Mathematics Education”
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The Context for Active Learning

Post-secondary mathematics education faces complex challenges, especially in mathematics courses that primarily serve students in their first two years of study. Some students take courses in the mathematical sciences as general education requirements, while others take mathematics as a major requirement in their discipline, which may or may not be mathematics intensive. Creating courses that adequately accommodate students with different backgrounds, expectations, needs, and goals is difficult, as is replicating practices that have been shown to be effective at different types of institutions, including community colleges, private four-year colleges, regional comprehensive universities, and public flagship universities. Because of this diversity of student backgrounds, desired learning outcomes, and institutions, there is no single classroom practice that can effectively address all of these challenges in all courses.

In addition to these challenges for faculty, many barriers to success for our students remain in place. Pervasive problems caused by issues of equity and access, starting long before students begin post-secondary study (Cross et al., 2009; Leonard & Martin, 2013; Schmidt & McKnight, 2014), prevent or discourage many students from continuing in their study of mathematics and other STEM disciplines (Hsu, Murphy, & Treisman, 2008). Yet even well-supported and well-prepared students who intend to enter STEM fields face inherent barriers to success in our current mathematics education system, barriers that will likely remain for the near future. As the background document to the NCTM/MAA *Joint Statement on Calculus* (MAA/NCTM, 2012) states,

[T]he United States has fallen into a seriously dysfunctional system for preparing students for careers in science and engineering, guaranteeing that all but the very best [students] rush through essential parts of the mathematics curriculum [in high school] and then are forced to sit and spin their wheels while they try to compensate for what was missed.

Thus, university-level mathematics courses are part of a complicated broader context involving high-school Calculus, the AP exam system, dual and concurrent enrollment programs, and other factors.

The mathematics community has responded in multiple ways to these challenges and others. Most of the professional societies involved in mathematics education have released recommendations and reports on this topic, including the MAA CUPM *Curriculum Guides* (Barker & Ganter, 2004; Ganter and Haver, 2015), the MAA CRAFTY reports (MAA, 2004; MAA, 2011), the ASA *Curriculum Guidelines for Undergraduate Programs in the Statistical Sciences* (ASA, 2014), the AMATYC reports *Crossroads* and *Beyond Crossroads* (AMATYC, 1995, AMATYC, 2006), SIAM's *Modeling Across the Curriculum* and *GAIMME* reports (SIAM, 2012; SIAM, 2014; SIAM, 2016), NCTM's *Principles to Actions: Ensuring Mathematical Success for All* (NCTM, 2014), the ASA/MAA statement on qualifications for teaching an introductory statistics course (ASA/MAA), and AMTE position statements on topics such as equity and formative assessment (AMTE). Despite their different origins, these documents share common themes, as illustrated by the 2015 MAA report *A Common Vision for Undergraduate Mathematical Science Programs in 2025* (Saxe & Braddy, 2015). The *Common Vision* report is noteworthy given that it brought together leaders from AMATYC, AMS, ASA, MAA, and SIAM to collectively reconsider undergraduate curricula and ways to improve education in the mathematical sciences.

There has also been an increase in professional development workshops for mathematics faculty, such as those run by the Academy for Inquiry-Based Learning (AIBL), the MAA CoMInDS workshops (CoMInDS), Project NExT (Project NExT), AMATYC's Project ACCESS (ACCESS), and others. There has also been an increased research focus on undergraduate mathematics education, as evidenced by the growth of Research in Undergraduate Mathematics Education (RUME) over the past twenty years, as well as the recent launch of large-scale NSF-funded studies of college Calculus by the MAA (Bressoud, Mesa, Rasmussen, 2015). Related research studies are discussed in the 2013 statement *Meeting the Challenges of Improved Post-Secondary Education in the Mathematical Sciences* (Bressoud, Friedlander, Levermore, 2013). Across the broader STEM community, similar research has been conducted, for example the work described in the National Academy of Sciences Discipline-Based Education Research report (NRC, 2012). Beyond the realm of formal research, there are robust public discussions regarding teaching and learning currently taking place in the mathematical sciences; one prominent example of this is an article by George Cobb (2015) in *The American Statistician* which was supplemented in the online edition by nineteen invited responses.

One message that is common to these reports, programs, and research studies is that the use of student-centered pedagogies and active-learning strategies can play an important role in

addressing the challenges of teaching and learning mathematics at the postsecondary level, as well as in K-12 education.

The Role and Impact of Active Learning

Researchers have investigated the relative efficacy of various classroom practices that complement other elements of effective teaching such as having well-designed courses with goals and learning outcomes communicated to students, allowing students to synthesize new material and make connections with what they had previously learned, and providing students with timely feedback (Fink, 2013; Chickering & Gamson, 1987). Many of the “effective” classroom practices they identified fall under the umbrella of active learning (hereafter AL) techniques. The phrase “active learning” as it is currently understood dates to the early 1990s and the work of Bonwell & Eison (1991), building on the work of Revans (1983). AL refers to any classroom practice that engages students in activities, such as reading, writing, discussion, or problem solving, that promote higher-order thinking. Since many different types of activities can achieve these goals, there is not a unique definition of AL, either in popular use or in the research literature. AL includes simple learning initiatives such as punctuating a lecture with collaborative activities such as think-pair-share, using short reflective writing prompts, or using one-minute papers at the end of class. (Other simple examples can be found in Angelo & Cross [1993] and Part 2 of Barkley & Major [2016].) AL also includes more complex strategies such as Inquiry-Based Learning, team-based projects, and service learning.

There is a wide range of research that examines the efficacy of active learning methods. A recent landmark in AL research is a meta-analysis of 225 studies that concludes that AL techniques have a strong positive impact on student learning across STEM disciplines (Freeman, et al., 2014). In a study focused on mathematics courses, researchers at the University of Colorado at Boulder conducted a large-scale investigation of the impact of Inquiry-Based Learning (hereafter IBL) techniques (Laursen, 2013). Their conclusions include that IBL students reported higher gains than non-IBL peers across cognitive, affective, and collaborative domains of learning, that IBL students did as well or better than non-IBL students in subsequent mathematics courses, and that IBL courses had a strong positive impact on women’s learning gains, confidence, and desire to persist when compared to non-IBL courses. The MAA National Studies of College Calculus projects found that, when combined with a foundation of good teaching practices, AL techniques have a positive impact on student confidence in Calculus (Bressoud, 2015, 2016). A multi-part survey regarding AL in post-secondary mathematics is available at the AMS blog *On Teaching and Learning Mathematics* (Braun et al. 2015). Researchers across STEM disciplines have found similar results with AL techniques (NRC, 2012); for example, the Physics Education Research literature is well-established, with an online repository containing both basic and applied research (Physics Education Research Central).

AL techniques can play a particularly important role with regard to equity, diversity, and access in mathematics education. At the K-12 level, NCTM’s *Principles to Actions* (NCTM, 2014) includes equity and access as one of its six guiding principles for school mathematics. AL techniques are essential elements of the eight Mathematical Teaching Practices that support teaching and learning found in *Principles to Actions*. Many of these foundational principles and practices of K-12 mathematics that support equity, diversity, and access extend to the post-secondary level, e.g. through extensions of social justice pedagogy and culturally relevant pedagogy. Some of the most established examples of this are the many Emerging Scholars Programs (hereafter ESP) across the United States; a goal of these mathematics workshop programs is “to increase student achievement

by creating small diverse communities of learners who work on challenging mathematics in visible and collaborative ways” (Hsu, Murphy, & Treisman, 2008). A key component of most ESPs is the use of problem-solving workshops, in which students work on a combination of individual and small-group assignments. In common with many IBL classes, ESP workshops use AL techniques to create supportive learning environments; these environments, in turn, lead to higher achievement for members of groups that are traditionally underrepresented in mathematics (Laursen, 2013; Hsu, Murphy, & Treisman, 2008). For students from different socioeconomic, cultural, and educational backgrounds, and for students with different approaches to learning and social interaction, a supportive community of learners can be cultivated using AL techniques.

Implementing and Supporting Active Learning

The idea that active student engagement improves student learning is not new to mathematics. For example, Project NExT has been training new faculty members in AL (and many other innovations and strategies) since 1994 (Project NExT). While NExT’s biggest impact has been on small colleges, where there is a strong emphasis on teaching and learning, there are also examples of research universities committed to AL. For example, the AMS report *Towards Excellence* highlights early AL initiatives in several university mathematics departments with doctoral programs (Ewing, 1999). Further, the results from the MAA National Studies of College Calculus projects (Bressoud, Mesa, & Rasmussen, 2015) and the large-scale IBL study (Laursen, 2013) discussed previously include analysis of research-intensive departments with institutionalized support for faculty using AL techniques. Common features of successful post-secondary institutional programs involving AL include regular analysis of efficacy of placement procedures, student success in a course, and student persistence and performance in later courses.

Professional societies, institutions and departments each have roles to play in supporting faculty and students in the improvement of teaching and learning. The professional societies can support the effort through research on AL, dissemination of the results, and the creation of materials to give faculty a starting point for implementing AL. Departments and institutions can examine their current culture as it relates to learning and classroom innovations, for example through the following questions. Are faculty appropriately supported and rewarded for efforts to improve their teaching? Are students encouraged to recognize and shoulder the responsibility they have to learn? Are they supported with resources, learning spaces, access to technology, and a campus culture that embraces participation in class, as well as serious effort outside of class? Are course materials and environments inclusive of students’ cultural and social backgrounds?

Some approaches encouraging the adoption of new pedagogies at the post-secondary level are much more effective than others (Henderson & Dancy, 2011). These include providing material that is shared broadly and is readily modifiable, providing dynamic social interactions along with research data (because personal connections increase the impact), and acknowledging situational constraints that inhibit pedagogical change along with the need to work to overcome such constraints. Departments, institutions, and professional societies should take these into account when planning professional development programs for mathematics faculty. It is particularly important that senior faculty take a leadership role in supporting and vetting changes to pedagogy, and that a dedicated group of faculty monitor the efficacy of departmental use of AL methods. Further, a recognition is needed that effective implementation of AL techniques requires a substantial learning curve for both faculty and students, and that poor implementations of AL techniques can be detrimental. For example, data from the MAA Calculus Study indicate that when

AL methods are employed without a foundation of effective teaching practices, there can be a negative net effect on students' learning and persistence (Bressoud, 2015, 2016). In order for AL techniques to be effective, there must be a commitment to incremental implementation and a broad spectrum of support for related components of high-quality teaching and learning.

Broad support is required due to the existence of various barriers to adoption of AL methods, including concerns about being able to cover required course content, difficulty in implementing AL in large classes, and increased preparation time. There are also potential challenges for new AL adopters, including having students who are unwilling to participate, receiving negative teaching evaluations, facing criticism by peers, and overcoming discomfort or inexperience with AL methods. Beyond these barriers, it is a common belief that teaching skill is relatively immutable or innate, rather than something that can be developed. Such views may restrict a faculty member's participation in professional development of teaching (Thadani, Breland, & Dewar, 2010, 2015), just as similar beliefs about mathematical talent can hold students back (Dweck, 2006, 2007). Support from department leadership and administrators is necessary, so that faculty have access to professional development when implementing AL methods. Other financial costs are sometimes associated with AL, such as obtaining software and reconfiguring classroom spaces. Moreover, time spent on effective teaching is often undervalued within the academy compared to time spent on research. As a result, it can be difficult for faculty and department leadership to find the financial and human resources required to implement and sustain AL methods successfully across the curriculum.

The most important aspect of supporting AL techniques is to recognize that there is not "one right way" to teach. Instead, there is a spectrum of AL methods, techniques, and environments in which students can be effectively engaged in the process of learning. Through identification of a wide array of such techniques, mathematics faculty and departments can select those that best fit their needs and that can be adapted for their local context. Developing expertise with unfamiliar teaching techniques is an incremental process, one that is best conducted in partnership with a community of colleagues, and with supportive resources from professional societies. The more that faculty, departments, institutions, and professional societies can provide time, resources, and support for these communities and their processes of improvement, the better we will be able to support the needs and aspirations of our students.

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