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Chapter

Dimensions for Development and Implementation of Active Learning in Higher Education

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Abstract

This chapter focuses on accessible active learning (AL) strategies that promote equitable and effective student-centered instruction for higher education. Although there is not a consensus definition of AL across disciplines, principles of AL include attention to student engagement with content, peer-to-peer interactions, instructor uses of student thinking, and instructor attention to equity. A variety of AL strategies vary in complexity, time, and resources, and instructors can build up repertoires of such teaching practices. The field needs cultural change that moves away from lecture and toward AL and student engagement as the norm for equitable and effective teaching. Although such cultural change needs to include instructor professional learning about AL strategies, it also needs attention to collective beliefs, power dynamics, and structures that support (or inhibit) equitable AL implementation. This chapter provides frameworks for sustainable change to using AL in higher education, as well as research-based findings around which AL strategies are easy on-ramps for novice instructors. This chapter also provides a few specific examples of structures that support AL—course coordination and peer mentoring—and provides questions one may pose in attempting to spur cultural change that centers AL.

Keywords: higher education, mathematics, professional development, inquiry-based mathematics education, equitable and effective

1. Introduction

In higher education, Active Learning (AL) has many facets and varying definitions across content areas. Even within STEM fields, AL varies in its application. In a chemistry lab, AL can focus on the instructor's ability to promote inquiry while the engagement originates from the lab itself. In a mathematics classroom, AL can focus on students engaging in a cognitively demanding task while the instructor assesses their work. One common theme through the definitions of STEM AL is that AL actively engages students in the content during class [1–3]. Contextualizing the verb *engage* is where definitions diverge relative to content area. Most definitions of AL

aggressively contrast AL with traditional lecture, where few questions are posed by the instructor and no activities exist that engage each student [2, 4].

The reason that AL has gained so much attention in higher education over the past two decades is the mountain of evidence demonstrating its value *when done properly*. Reference [5] illustrates how underrepresented STEM courses narrowed the achievement gap when AL was implemented in a student-centered method. Research across multiple classrooms across four universities yielded significant evidence that a variant of AL, inquiry-based learning, had profound impacts on men's and women's performance (not enough studies have focused on non-binary or genderqueer individuals to make similar claims yet) and high retention for women in college mathematics [4]. The National Academies of Sciences, Engineering, and Medicine released their first draft of the policy document [6]. Within [6], evidence-based research articulates a framework with seven principles, the first of which is AL.

Current research also warns that AL must be done equitably to be effective. Reference [7] illuminates that providing an AL activity is not sufficient to overcome microaggressions against marginalized groups. For example, if a STEM instructor assigns students to collaborate on a task, but does not observe their progress, there is no guarantee that: (a) all students will be included and engaged; (b) individual accountability and collaborative work will both be achieved; or (c) those in positions of power or privilege within the group will not use that power to exert influence over the group. Fundamentally, the instructor needs to do more than initiate an AL activity: They must also establish classroom discussion norms as well as monitor and intervene for equitable and effective use of AL.

Now that we have established the value of AL in undergraduate education, we will dig deeper into a specific content area. We provide a robust context to demonstrate how to take AL frameworks and put them into practice. As AL varies significantly across disciplines within undergraduate STEM education, the rest of this chapter will focus on the context of undergraduate mathematics education. We will begin by defining AL in undergraduate mathematics education and providing context for undergraduate mathematics. We then will expand into the dimensions of the theoretical frameworks relative to this context and conclude with how to implement these dimensions using an example of peer mentoring professional development.

1.1 Definition of AL in mathematics

As aforementioned, AL has varying definitions that abound among researchers and practitioners. We adopt the synthesis approach explicated in [3], using a framework developed by the author for inquiry-based mathematics education (IBME), as a basis for a definition of AL. The framework in Reference [3] emphasizes four pillars for AL:

1. Students engaging deeply with coherent and meaningful mathematical tasks.
2. Students collaboratively processing mathematical ideas.
3. Instructors inquiring into student thinking.
4. Instructors fostering equity in their design and facilitation choices.

Like other definitions of AL, this framework focuses on students engaging with mathematics and peer-to-peer interaction. However, this framework also emphasizes the role instructors have in supporting that engagement and calls specific attention to equity and the need for instructor intentionality in this area.

Of note is that the IBME framework is built from inquiry traditions (inquiry-based learning and inquiry-oriented instruction) that emphasize curricula having a “longer-term trajectory that sequences daily tasks to build toward big ideas,” which allows for students to “reinvent or create mathematics that is new to them” [3]. Thus, it presents a conception of AL that is more complex than, for example, using a pause for reflection or a think-pair-share strategy in class. A variety of strategies can engage students, varying by level of complexity on the part of the instructor and the students. For example, one common, relatively simple AL strategy to employ is quick polling. In this strategy, the instructor may have all students vote in response to a question; these votes are tallied using technology or quickly by counting the number of hands/fingers/notecards raised. A more complex AL strategy might involve students working collaboratively in small groups to formulate mathematical definitions (e.g., definitions of polygons).

The notion that anything “not lecture” is AL provides a valid starting point for instructors moving away from direct instruction. However, the territory of “not lecture” is vast, with many nuanced combinations of time involved, the types of tasks, the roles and responsibilities of students and instructors in actively engaging in learning, and the depth of learning.

1.2 Mathematical context

1.2.1 Classroom

Teaching undergraduate mathematics can be done in many formats: (a) lectures, (b) student-centered classrooms, (c) recitation labs or supplemental instruction sessions, and (d) math emporiums. Lecture (often called teacher-centered instruction) is a form of direct instruction where the focus is on teacher presentation and explanation of concepts. In student-centered classrooms, the instructor focuses on student understanding over teacher presentation, which can take place in many forms, such as inquiry-based learning [4], flipped classrooms, and inquiry-oriented instruction [3]. In the student-centered setting, the instructor is more of a guide on the side rather than the sage on the stage. In recitation labs, the instructor reviews what was done in the lecture and often describes problems and tasks to help students better understand the material; supplemental instruction is more often used to describe “just-in-time” teaching of topics, such as covering review topics prior to regular course lessons. Supplemental instruction is often called a co-requisite course that students take alongside their regular mathematics course. In both recitation labs and supplemental instruction, students meet outside of regular class time, typically in smaller groups. In the student-centered classroom, high-cognitive-demand tasks in [8] engage students with inquiry-based lessons in [3] where new concepts may be introduced by the instructors but are quickly engaged in by the students. In math emporiums, students work at their own pace through a guided curriculum with aides nearby to provide feedback and support. AL can take place in any of these environments, but subtleties may affect implementation. For example, AL strategies likely will differ based on class size and learning goals—how you would engage students in a recitation lab or review session may differ from how you would engage students learning the content for the first time.

1.2.2 Instructor

Undergraduate mathematics courses are taught by a diverse range of types of instructors, including: (a) undergraduate teaching and learning assistants, (b) graduate student instructors, (c) post-doctoral faculty, (d) adjunct faculty, (e) teaching faculty, and (f) tenure-track or research faculty. Undergraduate teaching and learning assistants may lead recitations, support AL in large lectures, provide supplemental instruction, serve as tutors, serve as emporium assistants, or even teach first- or second-year undergraduate mathematics courses. Graduate students also often teach undergraduate courses and/or recitations, while post-docs, adjuncts, teaching faculty, and research faculty often teach undergraduate- and graduate-level mathematics courses. It is important to note that many instructors have never taken classes on education or pedagogy. This lack of pedagogical coursework makes the college instructor different from a secondary or primary school educator, who has most likely taken educational classes and chosen education as their vocation.

1.2.3 Examples of AL in undergraduate mathematics

Considering all the different classroom structures and instructor types, it is useful to share examples of what AL in undergraduate mathematics looks like, particularly regarding what the student needs to do and what the instructor needs to do. A foundational work for many of the AL strategies of today stemmed from *classroom assessment techniques* (CATs), a collection of many dozens of formal and informal ways for instructors to gather information from their students about students' learning, that started to promote methodical formative assessment at the university level [9]. Additionally, reference [10] focuses on collegiate instructors' use of CATs as a methodical approach to collecting student feedback to help improve teaching effectiveness, which has significant overlap with formative assessment. CATs also promoted students' self-assessment of their learning with open-ended learning experiences, providing examples to the students on how they may actively engage with the content. From these CATs, many AL methods evolved (e.g. think-pair-share, exit slips, muddiest point, concept maps). One important factor that CATs emphasized, which needs to be included with AL implementation, is an understanding of how the teacher is actively gathering student data *during* the AL activity [11]. The instructors' gathering of student feedback is an essential component of AL because otherwise, it can be demonstrated to be neither equitable nor effective [7, 11]. Reference [12] supports these conclusions and provides a more robust clarification for implementing AL strategies. Some professional developments have gone so far as to make sure that before an AL is used, the questions, "what is the student doing?" as well as "what is the teacher doing?" are asked [11]. Altogether, these examples describe AL as more than traditional lectures, but recent research has led to a more robust framework for AL in mathematics education.

1.2.4 AL national initiatives for change

The *Student Engagement in Mathematics through an Institutional Network for Active Learning* (SEMINAL, 2016–2022) project was a six-year project focused on understanding how mathematics departments change their culture so that AL is the norm for instruction rather than lecture. SEMINAL acknowledged the lack of a single

definition of AL within the literature and explicitly used several key ideas from the literature to build a robust understanding of AL. (For example, see [2] for a definition that includes an explicit connection to higher-order thinking.) SEMINAL adopted four pillars from [3] as a framework for AL [13]. Using this framework, SEMINAL studied several mathematics departments' implementation of AL across different transition points, from the start of their efforts to use AL to (for most) their sustained use of AL. SEMINAL conducted cross-case analyses to gain a better understanding of what AL meant and looked like for different stakeholders and institutional contexts. An analysis of 115 definitions of AL, collected via SEMINAL interviews, revealed that participants strongly connected AL to peer interaction and deep engagement in mathematics thinking [14]. Importantly, people within the same department held similar ideas among their definitions of AL, underscoring the importance of department culture in shaping conceptions of AL [14].

One significant product focused on AL, specifically from the SEMINAL project, shares several examples of how AL was implemented across the SEMINAL institutions, as well as strategies for addressing common challenges instructors faced when using AL [13]. The strategies employed in [13] align with guidelines from [15] for effective teaching practices, which was also a national initiative to focus on student-centered instruction.

The evidence in support of AL having a positive impact on student outcomes is consistent [5, 16]. Although the field is moving slowly toward more active engagement of students, there is mounting evidence that instructors are adopting more active pedagogical practices into what have been traditional lecture. For example, see [16]. Some departments have made intentional cultural shifts toward embracing AL [17, 18], with accompanying positive changes in student outcomes [19–21]. When instructors are focused on actively engaging students in discussing and doing mathematics, and instructors intentionally attend to issues of equity and inclusion, students pass at higher rates and have more positive attitudes toward mathematics [2, 5].

2. Equitable and effective AL

Although the positive evidence for AL is overwhelming, when instructors fail to intentionally attend to issues of equity and inclusion, classroom inequities can persist or be magnified [22]. Student voices in small group discussions can reflect the inequitable participation seen in lecture environments: students whose voices are privileged ask the questions and drive the discussions [7, 23]. Equity does not just happen by chance but takes intentionality and effort—as well as willingness to be uncomfortable—on the part of instructors [24]. Students tend to be accurate in their estimations of their instructors' degree of equitable practices and in how instructors respond to inequities like microaggressions [25]. Student perceptions of their instructors influence students' sense of belonging in classrooms and thus their desire to persist in education [26]. At the same time, few instructors talk about equity when asked to define AL [14]. Thus, the fourth pillar of AL—instructor attention to equity—is critical.

AL has taken center stage in the international and national arenas because it provides access to discussing ways in which to center your classroom on students. The National Science Foundation, Bill and Melinda Gates Foundation, and the Howard Hughes Medical Institute all sponsored reference [6], in which evidence-based research from the last 40 years is analyzed to provide a framework for equitable

and effective teaching methods in STEM classrooms. The first principle, students need opportunities to actively engage in disciplinary learning, is then expanded upon, sharing how AL “engages students in making sense of the world around them by engaging them in questioning, discussing, analyzing, and testing disciplinary concepts and approaches.” [6] Instructor attention to equity requires practice and intentionality; references [7, 12] provide up-to-date approaches to [10] for STEM courses through the lens of AL. Thus, United States Undergraduate STEM policy documents are accepting the evidence-based research supporting AL. The challenge for many colleges is how to implement these changes meaningfully and sustainably for their faculty and students.

3. Four frames of culture to sustain changes in AL

When implementing AL, there is necessarily an instructor-centric level in which individual instructors learn about and adopt AL strategies. However, there is simultaneously a departmental level, where the departmental culture (e.g., norms, beliefs, structures) can support and promote or discourage and inhibit AL. Sustained adoption of AL strategies seems to be most possible in a department with a supportive culture, so a key question is how to positively change departmental cultures to embrace AL [18]. Departmental culture can be understood through four frames by looking at: (a) the *people* involved, (b) their *power* dynamics, (c) their collective *beliefs*, and (d) the departmental *structures* (e.g., course coordination and common exams) [18, 27].

Adopting AL strategies takes individual instructors’ efforts, but sustainable implementation of AL takes more than one person in a department. Sustainable implementation takes a cultural shift; we apply the four frames of cultural change to understand what types of changes are involved (people, power, structures, and collective beliefs). For sustainable changes, it is helpful to form a team of people to lead the change efforts. In forming a team, key considerations include the size and diversity of the team. Effective teams typically include three to eight people [28], and include at least one person who is:

- passionate about improving equity/inclusion,
- adept in quantitative, qualitative research skills [data analysis],
- respected by the department as a good teacher,
- respected by the department as a thought leader (e.g., full professor), and
- has formal power in the department to implement changes.

In considering the diversity of the team, people’s social markers (e.g., gender identity, ethnicity); experience; rank; and inclusion of graduate and undergraduate students (e.g., student instructors and learning assistants) are all considerations to include and balance (people and power dynamics).

Additionally, effective change plans for sustainability from the outset [18]. This design includes planning for turnover among the people involved and therefore how to maintain institutional memory. Key questions include:

- How will you document what you are doing?
- Where will that documentation be stored and who has access?
- How will new members be brought on board and oriented to the work?
- How will progress be shared with the broader department?
- Do you want to conduct and publish research about your efforts (via an approved research plan reviewed by an Institutional Review Board) so you can share your findings beyond your institution?

When launching change efforts, not all changes are necessarily improvements, so it is important to also consider how to measure success. The first time someone tries a new pedagogical strategy, it may not go as well as hoped. In addition to collecting student achievement data (summative assessments/grades as well as formative assessments), consider looking at dimensions of student access (placement into courses, access to tutoring/learning supports), identity (how students can be themselves in the classroom and how their voices and experiences contribute to the teaching and learning), and power dynamics (how much students feel their voices and contributions are valued in the classroom).

To assist mathematics departments in augmenting change efforts, one project has focused on networking and disseminating novice college mathematics instructor (CMI) preparation by creating a tool to allow colleges to quickly identify what other colleges have done to implement student-centered (e.g., AL) and inclusive teaching methods [29]. In 2022, this project conducted a national survey, sent to hundreds of people responsible for supporting learning about teaching by novice college mathematics instructors (e.g., university department chairs, course coordinators, workshop facilitators, seminar leaders). Results are being used to generate a tool (CMI Prep Design Tool) for mathematics departments to design, build, and tune local programs for preparing the next generation of college mathematics instructors. Fundamentally, this design tool is helping mathematics department AL change agents quickly and effectively sort through existing resources and community connections to develop and sustain AL teaching methods.

4. Levers for implementing and sustaining AL

Many potential structures, or *change levers* [16], support the implementation and sustainment of AL (e.g., placement into courses, course coordination, instructor professional development, supports for students outside the classroom, instructor mentoring). We will highlight two examples: coordination and peer mentoring.

4.1 Coordination

Coordination is a main structure that many departments use to help support instructors of the same course and, thus, a natural place to support AL within that course. Coordination can be used as a structure to start AL (for example, see [20]) but is equally as important for sustaining AL and bringing in other structures

(like professional development). Instructor meetings, often led by the role of the coordinator, can be a place for instructors to build collective beliefs and strategies for using AL. (For example, see [30].) Coordination can be a reason for building rich materials or having instructors collectively edit and discuss common materials. (For example, see [31].) Coordination can also support student buy-in. Several institutions such as the University of Michigan and the University of Nebraska-Lincoln brand their coordination programs and approach to AL, which reinforces to students that the department as a whole is supportive of AL (rather than just one instructor). These are all examples of how coordination can become a structure that helps share the workload of implementing and sustaining AL.

4.1.1 Supportive structure, learning assistants

In addition to course coordination, other departmental structures can be helpful when planning sustainable changes with AL. Three such structures are undergraduate learning assistants (LAs), assessment, and connecting change efforts to institutional priorities. The undergraduate LA model is a specific undergraduate teaching and learning model that supports AL in STEM. Building on the success of the model in disciplines such as physics, more mathematics departments are implementing this model in large-lecture courses. LAs receive pedagogical training on AL strategies and meet regularly with the instructor(s) of the course [32–34]. They typically guide students working in small groups on mathematical tasks. Thus, LAs act as an additional instructional figure in the classroom, ensuring that students have more opportunities for support and different ways to think about content. Furthermore, LAs can provide critical feedback to instructors about how students understand content and interact in groups [35, 36].

4.1.2 Supportive structure, assessment

When adopting AL, the focus of learning necessarily leans toward conceptual understanding, mathematical reasoning, and mathematical communication. This focus can be at odds with procedural assessments. Thus, most instructors find it necessary to update assessments to align with these new foci. When asking students about their course experiences, the most common complaint was around the apparent disconnection between assessments and work done during class [37]. Students get frustrated by this type of disconnect because they focus on the difference in perceived difficulty between the mathematical tasks completed during class and those on exams, with problems on the exams being much more challenging. Thus, students tended to perceive exams as being unfair and to place the blame for the disconnect on instructors. When departments had common exams, students either perceived their instructors as ill-informed about the assessments or as allies against unfair assessments; the latter tended to happen when students described positive relationships with their instructors. Thus, it is critical to align instructional methods and desired learning outcomes with assessment methods and types.

4.1.3 Supportive structure, strategic planning

Most institutions of higher education have some type of strategic plan or benchmark goals. Aligning the outcomes of AL with such a plan or goals can help prioritize

efforts and evoke resources (time and funding) to support those efforts. Key questions to pose include:

- What specifically are we trying to accomplish?
- How do these goals align with the department, college, and/or institutional strategic plans?
- Where should we start? What should we prioritize?
- What changes might we introduce and why?
- How will we know that a change is actually an improvement?
- What data/progress will be convincing to those who hold the resources?
- In considering priorities, two additional considerations are to explore what education research has demonstrated as important and to talk with students (through focus groups or asking them to write reflective journals) to understand their experiences and perceptions.

4.2 Peer mentoring

To support college instructors' adoption or adaptation of AL strategies, the incorporation of a mentoring structure, whereby instructors with experiences or training actively support others' use of AL strategies, is one way to address potential barriers. For example, mathematics education researchers have recently implemented and sustained peer-mentoring programs in mathematics and statistics departments in universities in the U.S. [38, 39]. In one peer-mentoring program, for instance, graduate student instructors who are experienced and effective at using AL strategies in undergraduate mathematics and statistics instruction attend a semester-long training to become peer mentors [40]. The training focuses on: (a) how to provide constructive feedback when observing college math instructors teach and (b) how to facilitate critical conversations in small group settings to develop a community of practice among graduate student instructors around AL in collegiate mathematics and statistics teaching.

Each mentor is then grouped with approximately four first- or second-year graduate student instructors (called *novices*) who are all teaching the same or similar courses. The small groups meet every other week for an hour for an entire academic year, with the mentor facilitating these small group discussions. Additionally, the mentor observes each novice approximately three times a semester for two semesters because changing one's beliefs, attitudes, and/or dispositions requires more than one semester [41]. During these observations, the mentor uses the Graduate Student Instructor Observation Protocol (GSIOP) [38]. This GSIOP draws from [15] by considering lesson design practices, teacher facilitation, and classroom practices that promote student engagement. For instance, the mentor considers student engagement by focusing on whether students engage with mathematical ideas, different strategies, their peers, and formative assessment strategies. After each observation, the mentor has a post-observation conversation with the novice, highlighting areas that are

supporting or potentially inhibiting student engagement, with a Socratic discussion that elicits specific suggestions or ideas for continued improvement and growth.

4.2.1 Peer mentoring research

An analysis of observation and post-observation conversation data from 293 observations across two years at three universities illuminated the AL strategies novices most frequently used in their teaching and discussed with their mentors in post-observation conversations [41]. The researchers found that mentors tended to regularly observe and discuss three AL strategies above all others

- *quick poll*: have all students vote in response to a question. Votes can be tallied using technology or quickly by counting the number of hands/fingers/notecards raised.
- *think-pair-share*: have students answer a question individually, then compare their answers with a partner and synthesize a joint solution to share with the class. Can be used with or without high-tech or low-tech clickers.
- *Conceptually based teacher questioning (C-BTQ)*: a teacher's questions are used in tandem with tasks/activities for students to investigate, discover, and/or apply concepts for themselves. For instance, after the instructor identifies an idea or concept for mastery, a question is posed that asks students to make observations, pose hypotheses, and speculate on conclusions. Then students are asked to tie the activity back to the main idea/concept.

Instead of listing a broad category like inquiry-based learning, these researchers explain that they focused specifically on C-BTQ because it operationalized a classroom practice that mentors could observe. It is important to note that teacher questioning alone is not an AL strategy [42]; however, the researchers included C-BTQ so that mentors could concretely see examples of inquiry-based learning used with C-BTQ, where novices elicited responses from all students. The findings from this study provide a means to create future studies to target the top three AL strategies (as natural in-roads for using AL strategies more broadly) together to determine how they can interact and work together for improving the use of AL with novice college STEM instructors.

4.2.2 Four frames and peer mentoring

The four frames (people, power, structures, and beliefs) play directly into the peer-mentor model for sustainable change. We will start with the people and departmental structures. The foundation for the peer-mentoring program requires administrators to be committed to novices' development. This constraint can be challenging as many administrators view graduate student instructors as a transient teaching workforce, changing every two to six years. However, departmental administrators recognize that graduate students often teach a large number of lower-level mathematics courses in the current structure of undergraduate mathematics education [43]. Despite being transient, graduate students have a large impact on the college experience for many undergraduate students. Structurally, graduate students are a

key teaching group whose views of teaching may be more pliable than tenure-track research professors. With respect to power, it is also important to recognize that peer mentoring is different from faculty mentoring. In [44] the authors found that faculty who mentored on teaching could over-influence novices because the novices felt unsafe to disagree with their faculty mentor/advisor, but novices had no problem sharing their opposing opinions with fellow peers. This difference is due to the power dynamic often created between faculty and graduate students. This distinction may seem subtle, but it is critical to providing equitable trust between the mentor and mentee. Another advantage of diffusing power in the mentor-mentee structure is that it allows for the mentor and mentee to be able to promote an open community among graduate students, where it is acceptable to ask for help with teaching. This dynamic creates a powerful belief among graduate students that sharing and discussion of pedagogy is not only acceptable, but meaningful for building a community of practice [45] around teaching. Ultimately, this change is sustainable due to the minimal funding it takes to train and mentor novices versus the impact on improving student success and lessening student complaints.

5. Conclusions

In this chapter we gave two explicit examples of structures that can be leveraged to support AL: coordination and peer mentoring. However, multiple additional institutional structures can and should be considered when initiating and implementing AL (e.g., placement processes). Indeed, sustainable change efforts activate multiple change levers to be effective. Although the examples we provide are situated in mathematics contexts, lessons learned can be broadly applied to other STEM fields. For example, see [46], which supports mathematics departments in creating graduate student professional development programs centering AL, and has expanded to physics and chemistry. Furthermore, many frameworks and strategies used are shared across STEM (i.e., the four frames are about STEM departments broadly). Also, AL definitions like the four pillars [3] can be broadly applicable for other content areas, to focus on student engagement in content, peer-to-peer interactions, instructor use of student thinking, and instructor attention to equitable practices.

Implementing AL necessarily requires instructors to learn about how to support student engagement for learning, with intentional attention on equitable teaching practices. To effect departmental culture change and to sustain AL beyond individual instructors, concerted efforts need to be made to change the departmental cultures with attention to the people involved, their collective beliefs, the power dynamics at play, and departmental structures to promote and support AL. The unfortunate tradition of teaching as direct instruction does not serve most students well [7]; instruction needs to actively engage students to result in better student outcomes for learning. AL strategies need to be implemented with attention to equitable practices, so that the inequitable patterns of discourse that permeate society are not perpetuated in small groups.

5.1 The myth of time and AL

One common concern about implementing AL is the additional time it takes to implement it well, as compared to lectures. However, consider how much students

are learning from listening to a lecture and how long that information is retained. If students are retaining only half the material about which they were lectured, instructors could think about cutting 25% of the content out of a course and implementing active learning to develop students' conceptual understanding and strategic problem-solving skills. At the end of such a course, students retain more than direct instruction and are better able to apply their mathematical knowledge to future situations [2, 5].

5.2 Acceptance of tensions

Implementing AL strategies comes with tensions. Change is not comfortable, and structuring teaching around what students know and need is a different approach than preparing lecture notes. Expect resistance from students and instructors when the norms change; students who expect to passively listen to lectures may need to be convinced of the value of active engagement. Part of the work of change is often a need for the departmental culture to value teaching improvements—if the institution and department value research over teaching, it can be hard to convince instructors to invest the time necessary to implement AL. The tension of balancing the demands of research, teaching, and service for instructors is not an easily resolved issue. Another tension is between needing time to implement change processes versus the need for results. The administrators providing resources to enable changes want to see immediate positive results (typically student grades/achievement), but initial impacts may be only minimal progress because teaching differently and changing cultures is hard, takes iterative work, and need thoughtful use of data to make decisions. The higher education system is set up to value achievement data, but in the absence of access, identities, and power, true progress will be impeded. Thus, teams wanting to implement AL should have multiple discussions about anticipated tensions, challenges, and barriers, and how to adapt strategies, detour around or remove barriers, or address challenges to make progress.

5.3 Future pathways for implementation and research

One of the unique distinctions for STEM faculty teaching undergraduate courses is that STEM faculty most likely did not take education classes. Unlike a secondary-school physics teacher, the average physics professor did not take educational courses because their motivation as a graduate student was on researching physics, not improving their teaching. This difference makes higher education's implementation and use of educational research much more difficult to integrate because faculty may not be interested in learning how to read educational research, how to use education research, or how to do education research. This lack of interest can be a barrier to AL implementation without the appropriate and sustainable change to departmental culture. Our two examples, coordination and peer mentoring, provide concrete examples of how the four frames can help implement AL within mathematics undergraduate courses. Many other pathways exist because there is no one-size-fits-all method of professional development to move a department toward using AL appropriately. However, identifying the change that has been accomplished and characterizing the underlying factors (as the four frames have done in this chapter) allow these examples to be transferable so that AL can be shared with all instructors equitably and effectively.

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Conflict of interest

The authors declare no conflict of interest.

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