Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #47579

Challenges and strategies of STEM instructors in adopting active learning: Insights from a hand-search of International Journal of STEM Education

Xiaping Li, University of Michigan

Xiaping Li is a Ph.D. student in Engineering Education Research at the University of Michigan. Her research interests encompass faculty development and instructional change, neurodiverse college student learning experiences and outcomes, GenAI in higher education, and cognitive sciences. She holds a B.S. in Hydrology and Water Resources Engineering and an M.S. in Geological Sciences.

Challenges and strategies of STEM instructors in adopting active learning: Insights from a Hand-search of International Journal of STEM Education

Abstract

The literature review was conducted to synthesize the challenges and strategies faced by STEM instructors in adopting active learning, drawing on 42 empirical studies published between 2014 and 2024 in the International Journal of STEM Education. Active learning refers to evidence-based, student-centered teaching methods that engage learners through individual or group activities, yet it remains underutilized in STEM higher education despite well-documented benefits. This conference paper presents the preliminary results of this literature review project, including the nature of articles included, the change theories applied, and the primary challenges and strategies of STEM instructors in adopting active learning. Through hand-searching this high-impact journal, three methodological approaches (15 qualitative, 10 quantitative, and 17 mixed-methods studies) were identified, with nearly all investigations conducted in the United States, where educators and funding agencies emphasize the importance of theoretical frameworks to guide instructional change. Thirty-seven studies explicitly delineated the theoretical frameworks shaping their research design and result interpretations, with ten papers incorporating multiple theories. Common barriers include substantial time commitments, limited institutional support, and resistance from students or colleagues, while effective strategies feature professional development programs, communities of practice, transparent communication about the benefits of active learning, and iterative refinement of instructional techniques. Because engineering stands at the intersection of STEM disciplines, many of these challenges and strategies are especially relevant to engineering educators, who navigate unique complexities in bridging theoretical, design, and practice-based content. In addition, the findings align closely with the mission of the Faculty Development Division and may inform faculty development initiatives aimed at broadening the adoption and efficacy of active learning in engineering and the broader STEM community.

Introduction

Active learning denotes student-centered instructional strategies that have been empirically demonstrated to transition students from passive listeners into active learners and critical thinkers, engaging them through individual or group activities and enhancing their learning outcomes [21], [44]. In this study, it includes student-centered, evidence-based, and inclusive instructional methods. American higher education has undergone two primary instructional shifts since the colonial era, progressing from recitation to lecturing and evolving toward student-centered instruction [79]. From the 1950s to the 1980s, the expansion of research institutions led to a national shortage of professionals [58]. During this period, higher education graduates often struggled to align their scientific training, which was focused on solving well-defined problems, with the ill-defined, real-world challenges encountered in the workplace [58]. As a result, educators intensified efforts to improve teaching quality, leading to the broader adoption of active learning strategies [7], [13], [79].

Active learning has proven advantageous in multiple educational settings, including face-to-face [21], [25], [44], [68], online [11], [32], [62], [76], and blended teaching modes [15], [24]. Despite these well-documented benefits, engineering and other STEM disciplines have experienced persistent challenges in effectively integrating active learning across various teaching formats [2], [6], [19], [43], [64]. Consequently, adoption of active learning has remained slower than might be expected, particularly in engineering programs that traditionally rely on extensive lectures with a focus on solving well-defined problems.

For instance, Hall et al. analyzed a shift from lecture-based to active-learning strategies in an MIT engineering course, examining motivations for this change and strategies to surmount implementation challenges [26]. Although some instructors made progress, the process remained difficult, in part because altering how a course is taught often requires deeper adjustments to teaching beliefs, classroom management, and course structure than altering *what* is taught [26]. Borda et al. also observed that STEM faculty, including those in engineering, encountered barriers, such as high workload demands and limited departmental support, even after completing professional development programs [8]. These findings are consistent with funding-agency recommendations (e.g., the National Science Foundation) that call for the application of explicit change theories to guide instructional transformation in higher education, recognizing the multifaceted challenges of shifting *how* one teaches.

Given this context, the present literature review was undertaken to explore STEM instructors' adoption of active learning and compare challenges and strategies identified in prior studies. Although the findings apply broadly, particular attention is devoted to engineering education, given engineering's close ties to other STEM fields. By synthesizing key themes across studies, this work aims to inform policymakers, researchers, and faculty developers seeking to support evidence-based, student-centered instructional methods.

Hand-searching was chosen because it fosters a detailed understanding of the research area, helps refine inclusion and exclusion criteria, and facilitates the identification of further search queries. The *International Journal of STEM Education* (IJSE) was selected for its high impact and commitment to research on STEM teaching and learning. Established in 2014, it aligns with a substantial rise in STEM-related education scholarship during the past decade. Papers published from 2014 to 2024 were screened, leading to the selection of 42 relevant empirical studies.

This project was organized around three core research questions:

- **RQ1.** What is the nature of the IJSE literature on the challenges faced by STEM faculty and the strategies they employ in adopting active learning?
- **RQ2.** What change theories or frameworks have been applied in guiding the included research?
- **RQ3.** What are challenges and strategies primarily discussed in the included research?

Results from this review underscore significant obstacles to implementing active learning and point to strategies, including faculty development initiatives, that can mitigate these obstacles. The analysis is highly relevant to the Faculty Development Division, as the findings suggest ways to better support engineering and other STEM instructors in successfully implementing evidence-based teaching. Furthermore, while integrating active learning can be challenging in any STEM field, engineering education presents an especially instructive case due to its strong connections to real-world problem-solving and its intersection with multiple scientific and mathematical domains. Because engineering students often take courses in physics, chemistry, and mathematics, the broader STEM context directly influences their academic journey and preparation for professional practice. By acknowledging and addressing the complexities involved, faculty developers and engineering education researchers can capitalize on active learning's proven benefits, ultimately improving teaching effectiveness and student success across STEM disciplines, with direct implications for engineering education.

Methods

Inclusion & Exclusion Criteria

Table 1 presents the criteria applied to determine whether papers were suitable for inclusion. Studies were required to focus on STEM instructors' adoption of active learning in higher education, explicitly report research methods and findings, and address challenges or strategies associated with implementing active learning.

Table 1. Inclusion & Exclusion Criteria

Criteria	Inclusion	Exclusion
Electronic citation	Electronically available title and abstract	No abstract available
Language	Reported in English	Reported in any language other than English
Publication date	Published 2014-2024	Published not in the period from 2014 to 2024
Setting	Higher education	Any educational levels but higher education
Empirical research	Articles with explicit reporting of research purposes, methods (participants, data collection, and data analysis), and findings.	Non-empirical research, theoretical articles, articles without explicit methods, e.g. book reviews, editorials, letters, policy papers, consultations.
Sample/ participants	Participants are STEM instructors or a majority of participants are STEM instructors; or instructional practices of STEM instructors	Participants are not STEM instructors: 1) teaching assistant or instructional assistants; 2) pre-service teachers; 3) teacher students or student instructors, and 4) faculty facilitators or change agent.
Phenomenon of Interest	A study is focused on exploring STEM instructors' adoption of active learning. It must discuss instructors' experience of using active learning in STEM courses. It also discusses or includes STEM instructors' challenges and strategies while adopting active learning in their classes.	A study must be excluded if it meets any of the following criteria: 1) Research does not focus on STEM instructors' adoption of active learning 2) Research does not include instructors' challenges or strategies
Document type	Peer-review Journal paper	Not peer-review journal paper, conference paper, dissertation, report

Adapt from [82].

Screening & Selection

Two stages of screening were conducted (Figure 1). First, all articles (*n = 507*) in the *International Journal of STEM Education* were screened by title and abstract against the inclusion and exclusion criteria. This step yielded 46 articles eligible for full-text review. Five of these were excluded because they did not meet the Phenomenon of Interest criterion, resulting in 42 final articles for data extraction.

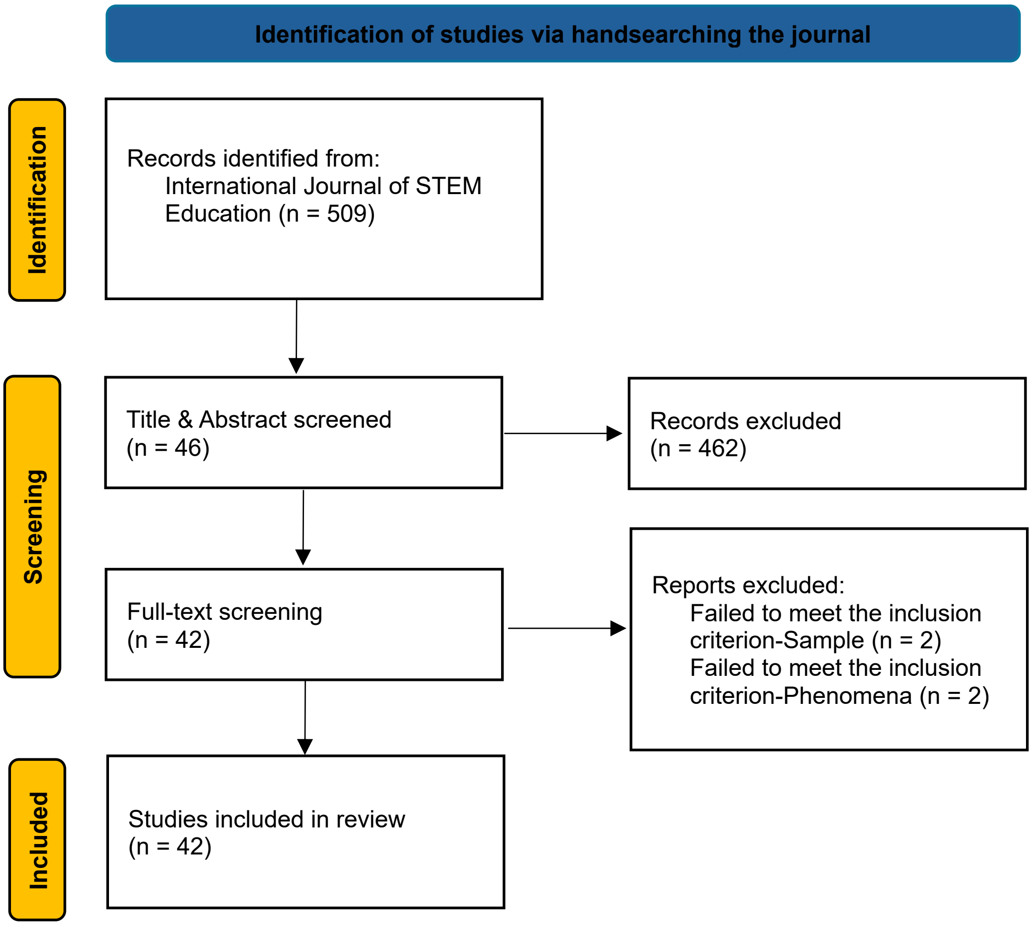

Figure 1. PRISMA (Adapted from [83])

Data Extraction & Analysis

The data extraction was guided by the following analytical questions, which were used to categorize and analyze the data. Analytical questions 1 to 6 address the first research question (RQ1), questions 7 and 8 address the second research question (RQ2), and the final analytical question pertains to the third research question (RQ3).

1. What is the research purpose and/or research questions?
2. What is the sample? Who are the participants? And sample size.
3. What research methods are used?
4. If any, what specific active learning strategies are examined in this article?
5. What disciplines does the article study?
6. Where was the study conducted? If not specified, then where are the authors' affiliation institutions?
7. What theoretical approaches (if any) are foregrounded?
8. Is the theoretical theory a change theory or framework?
    a. Yes
    b. No
    c. Not sure or N/A
9. What are the findings in terms of challenges and strategies?

Results

The nature of the IJSE literature

The annual number of published articles in the International Journal of STEM Education steadily rose from 2014, peaking in 2022 and then mildly declining thereafter. Conversely, the number of included articles remained less than 10 each year and reached its maximum in 2019 and 2022.

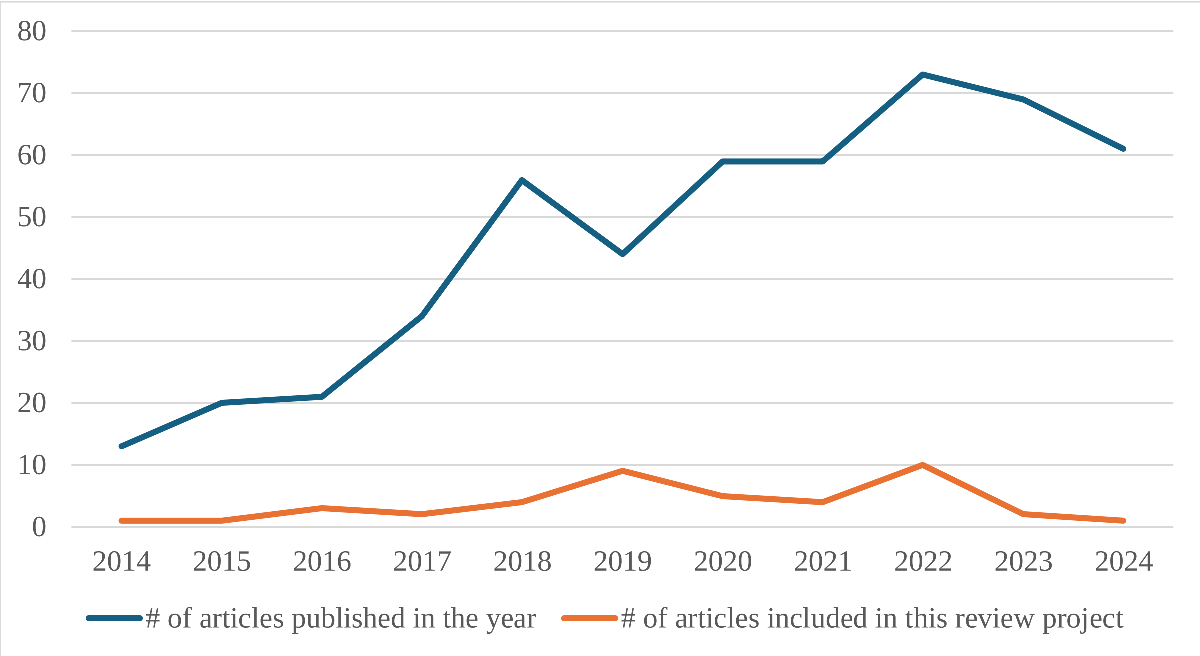

Figure 2. Numbers of Articles Published by International Journal of STEM Education (2014-2024)

In terms of the study sample, most studies collected data directly from STEM instructors (Table 2). However, four notable studies (i.e., Denaro et al. [16], Jackson et al. [30], Teasdale et al. [66], and Tomkin et al. [71]) primarily employed an observational approach, using the Classroom Observation Protocol for Undergraduate STEM (COPUS), Reformed Teaching Observation Protocol (RTOP), and Practical Observation Rubric to Assess Active Learning (PORTAAL). COPUS, for instance, provides a quantitative breakdown of class sessions into short intervals, categorizing both student and instructor behaviors into 25 distinct codes. These codes can be further classified into eight “analyzer” codes, eight “collapsed” categories, or a “novel” grouping aimed at differentiating learning activities. By structuring classroom interactions in this manner, COPUS enables researchers to systematically analyze instructional practices and student engagement patterns. While observational approaches offer valuable insights into real-time classroom dynamics, they differ from studies that primarily rely on faculty self-reports.

The research methodologies represented in the reviewed studies included quantitative (n=10), qualitative (n=15), and mixed-methods (n=17) approaches (Table 2), reflecting diverse strategies to investigate active learning in STEM education. Quantitative methods were frequently used for large-scale surveys and data analysis, as seen in studies like Foote et al. [20] and Landrum et al. [37], which analyzed instructor adoption patterns and instructional climates. Qualitative approaches, such as case studies and thematic analysis, were employed to provide in-depth insights into specific practices, barriers, and instructor experiences, exemplified by Koretsky et al. [34] and Tharayil et al. [67]. Mixed-methods research, such as work by Lund and Stains [41] and Tinnell et al. [70], combined surveys, interviews, and classroom observations, offering a more comprehensive perspective on the factors influencing instructional change.

Furthermore, an intriguing departure from the norm was observed in Hayward and Laursen's study [27], which delved into the final phase of instructional change using social network analysis to examine communication patterns within a group email list and record relationships. This distinctive methodological choice sets this particular study apart from the rest in the literature review.

Regarding other attributes of the reviewed papers, a noteworthy observation arises from the Country column in Table 2, where all entries are exclusively from the USA. This revelation is rather surprising and may suggest either a concentration of studies on the challenges and strategies of STEM instructors' adoption of active learning within the USA or a tendency for studies conducted in other countries to prefer alternative journals for publication.

A subset of twelve studies focused explicitly on engineering instructors or courses. Among these, Tinnell et al. [70] and Tharayil et al. [67] exclusively investigated engineering faculty, utilizing semi-structured interviews to examine instructional practices. The reviewed literature indicated that active learning strategies frequently used in engineering education include collaborative problem-solving, peer discussions such as think-pair-share, team-based projects and assignments, case-based learning, and incremental task scaffolding. Given the nature of engineering education, which integrates problem-solving, design projects, and laboratory-based learning, these findings underscore the need for discipline-specific approaches to implementing active learning effectively.

Change theories

Change theory refers to an evidence-based framework of ideas that extends beyond single change initiatives, generalizes observations of changes, and enriches collective knowledge to explain how change occurs (adapted from [53], [80], [81]). Table 2 indicates a synthesis of the theoretical frameworks applied in the reviewed papers, addressing the second research question: *What change theories or frameworks have been applied in guiding the included research?*

Among 42 articles, 37 studies explicitly delineated the theoretical frameworks shaping their research design and result interpretations, with 10 papers incorporating multiple theories (Table 2). The most common change theories applied included Rogers' model of the innovation-decision process, Dormant's CACAO (Change, Adopters, Change Agent, and Organization) model, and Communities of Practice, e.g., [71].

I also noticed that scholars tended to apply more than one theory to guide their research since 2019. For example, Quardokus Fisher et al. [52] applies Relational Expertise as a guiding framework to examine how faculty develop the ability to navigate institutional and disciplinary boundaries to support instructional change. The authors also integrated communities of practice to explain how faculty interactions shape departmental teaching cultures and facilitate the spread of evidence-based instructional practices. Additionally, the study employed social network analysis as a methodological tool to map faculty teaching discussions, identify key connectors, and assess how social structures influence the adoption of teaching innovations. Applying multiple theories may provide a more comprehensive understanding of STEM instructors' adoption active learning [53], [81].

Table 2. Summary of included papers (sort by year)

Author	Year	Research purposes/Objectives	Sample	Methods	Country	Specific STEM disciplines	Theoretical or conceptual frameworks	Change theory?	Specific active learning teaching methods mentioned in the article
Foote, K. T., Neumeyer, X., Henderson, C., Dancy, M. H., & Beichner, R. J.	2014	To examine how the SCALE-UP model has spread across disciplines and institutions and to provide insights into its dissemination and implementation	659 faculty members familiar with SCALE-UP	Quantitative	USA plus 16% outside United States	Physics, Biology, Chemistry, Engineering (7.5%), Mathematics and Statistics, etc.	Diffusion of Innovations theory	Yes	Teamwork, Problem-solving, Student presentations, Reduced lecture time, Collaborative and interactive learning in redesigned studio-style classrooms
Lund, T. J., & Stains, M.	2015	To explore how disciplinary and contextual factors influence the adoption of student-centered teaching in STEM fields.	54 faculty survey respondents and 28 classroom observations.	Mixed	USA	Biology, Chemistry, Physics.	Diffusion of Innovations theory	Yes	Peer instruction, Think-pair-share, Clickers, Concept inventories, POGIL, Case studies, Problem-based learning.
Czajka, C. D., & McConnell, D.	2016	To evaluate the use of a situated instructional coaching model for faculty professional development aimed at supporting active learning and student-centered teaching practices in STEM	One geoscience faculty member (Instructor M) and a graduate student coach	Mixed	USA	Geoscience	1) Interconnected Model of Teacher Professional Growth; 2) Collaborative professional development model	Yes	Group discussions, student debates, think-pair-share, problem-solving activities, and use of conceptual multiple-choice questions (ConcepTests)
Knaub, A. V., Foote, K. T., Henderson, C., Dancy, M., & Beichner, R. J.	2016	To investigate the role of classroom space in the successful and sustained implementation of SCALE-UP (Student-Centered Active Learning Environment with Upside-down Pedagogies)	21 faculty, administrators, and staff from 21 successful SCALE-UP implementations across 19 institutions	Qualitative	USA	Physics, Biology, Mathematics, Chemistry, Engineering.	Diffusion of Innovations theory	Yes	Collaborative problem-solving, team-based learning, integration of lab and lecture
Pelch, MA, & McConnell, DA.	2016	To explore how material development for the InTeGrate project influenced the pedagogical beliefs of geoscience instructors	21 faculty developing geoscience teaching materials	Mixed	USA	Geoscience	Clarke and Hollingsworth's interconnected model of professional growth.	Yes	Case-based learning, collaborative design of teaching materials.
Landrum, R. E., Viskupic, K., Shadle, S. E., & Bullock, D.	2017	To develop and validate tools for assessing STEM instructional climate and adoption of evidence-based instructional practices (EBIPs)	528 faculty at Boise State University	Quantitative	USA	Not specific	Dormant's CACAO change model	Yes	Not specific

Shadle, S. E., Marker, A., & Earl, B.	2017	To understand faculty perspectives on drivers and barriers to implementing STEM education reforms and to analyze departmental differences in these perspectives	169 faculty and staff from 12 departments at Boise State University	Qualitative		Various STEM fields, including biology, chemistry, engineering, and physics	Dormant's Chocolate Model of Change	Yes	Not specific; focused broadly on faculty engagement with evidence-based instructional practices (EBIPs).
Tharayil, S., Borrego, M., Prince, M., Nguyen, K. A., Shekhar, P., Finelli, C. J., & Waters, C.	2018	To understand faculty perspectives on drivers and barriers to implementing STEM education reforms and to analyze departmental differences in these perspectives	17 engineering instructors who self-identified as frequent practitioners of active learning	Qualitative	USA	Engineering disciplines, including chemical, mechanical, civil, and electrical engineering	Explanation and facilitation framework for mitigating student resistance.	No	Case-based learning, think-pair-share, team problem-solving, and incremental task scaffolding
Auerbach, A. J. J., & Andrews, T. C.	2018	To investigate the pedagogical knowledge that biology instructors use when implementing active learning in large undergraduate courses	77 college biology instructors with active-learning experience	Qualitative	USA	Biology	Model of teacher professional knowledge and skill	No	Group work, think-pair-share, formative assessments, and structured discussions
Hayward, C. N., & Laursen, S. L.	2018	To examine the role of online support networks in sustaining instructional changes among mathematics instructors after professional development workshops	35 mathematics faculty who attended professional development workshops	Mixed	USA	Mathematics	Lewin's three-stage model of change (unfreezing, changing, refreezing)	Yes	Inquiry-based learning
Koretsky, M., Keeler, J., Ivanovitch, J., & Cao, Y.	2018	To compare the use of two active learning tools—Audience Response Systems (ARS) and Guided Inquiry Worksheets (GIW)—in large enrollment STEM courses in biology and engineering, focusing on how they promote student sense-making	2 instructors	Qualitative	USA	Biology and Chemical/Environmental Engineering	N/A	N/A	Conceptual check-ins, conceptual development, (scaffolded) problem-solving problem-solving
Johnson, E., Keller, R., Peterson, V., & Fukawa-Connelly, T.	2019	To investigate the instructional practices of undergraduate mathematics instructors in abstract algebra courses and identify individual and situational factors influencing their use of lecture and non-lecture pedagogies	219 instructors teaching undergraduate abstract algebra courses	Quantitative	USA	Mathematics	1) New institutionalism framework; 2) Faculty beliefs theories	Not sure	Group discussions, inquiry-based learning

Tinnell, T. L., Ralston, P. A., Tretter, T. R., & Mills, M. E.	2019	To investigate the long-term impact of Faculty Learning Communities (FLCs) on sustaining pedagogical changes, particularly collaborative student learning techniques, among engineering faculty	12 engineering faculty from two FLC cohorts	Qualitative	USA	Engineering (spanning multiple departments, including mechanical, electrical, and civil engineering)	Faculty Learning Communities structure that incorporated the Community of Practice features that emphasized shared growth	Yes	Collaborative student learning techniques, including: Small group problem-solving, peer-to-peer discussions, and team-based projects and assignments.
Olmstead, A., Beach, A., & Henderson, C.	2019	To develop a context-specific model for understanding how instructional change teams work in undergraduate STEM education	28 leaders of instructional change projects in higher education institutions	Qualitative	USA	Not specific	N/A	N/A	Not specific
Scanlon, E., Zamarripa Roman, B., Ibadlit, E., & Chini, J. J.	2019	To develop a framework and methodology to analyze the purposeful modifications instructors make to Research-Based Instructional Strategies (RBIS) and the reasons behind these changes	4 instructors teaching introductory physics courses.	Qualitative (supported by quantitative frequency)	USA	Physics	1) Modification Identification Framework integrated with 2) Revealed Causal Mapping model	No	Student-Centered Active Learning Environment with Upside-Down Pedagogies (SCALE-UP) which integrates: 1) minimized lecture time, 2) group work, 3) combined lecture, lab, and recitation time, and 4) students solving real-world problems collaboratively
Tomkin, J. H., Beilstein, S. O., Morphew, J. W., & Herman, G. L.	2019	To investigate whether participation in Communities of Practice (CoPs) correlates with increased use of active learning practices in large undergraduate STEM lectures	CoP (25) and Non CoP (35) instructors' lectures	Quantitative	USA	Broad STEM fields: Engineering (Civil and Environmental Engineering, Mechanical Engineering, Integrative Biology, Computer Science, Industrial Engineering, Electrical and Computer Engineering, and Materials Science and Engineering), Chemistry, Biology, Physcis, Mathematics	Communities of Practice framework	Yes	Group problem-solving. Use of student response technologies (e.g., iClickers). Peer instruction and guided discussions.
Bathgate, M. E., Aragón, O. R., Cavanagh, A. J., Waterhouse, J. K., Frederick, J., & Graham, M. J.	2019	To examine how perceived supports and barriers relate to the implementation of evidence-based teaching (EBT) practices among STEM faculty trained in EBT	584 faculty and instructors from college science disciplines	Mixed	USA	Primarily science disciplines	Theory of Planned Behavior (Ajzen, 1985, 2011)	Yes	The 19 EBT practices assessed included: 1) active learning techniques like group discussions and exercises, 2) inclusive teaching practices, such as metacognition and addressing implicit biases, 3) backward design and formative assessments

Quardokus Fisher, K., Sitomer, A., & Koretsky, M.	2019	To explore how social network analysis (SNA) can be used to develop relational expertise and catalyze instructional change initiatives across STEM disciplines within a university	142 faculty memebers from 7 STEM disciplines	Mixed	USA	Biology, Chemistry, Physics, Mathematics, and three Engineering disciplines (Chemical, Civil, Mechanical)	1) Relational Expertise Framework 2) Communities of Practice	Yes	Evidence-Based Instructional Practices (EBIPs): Interactive engagement with formative feedback and cooperative learning approaches
Sturtevant, H., & Wheeler, L.	2019	To develop and validate the Faculty Instructional Barriers and Identity Survey (FIBIS) as a tool to systematically understand: 1) STEM faculty's use of and satisfaction with evidence-based instructional practices (EBIPs). 2) Barriers to EBIP implementation. 3) The relationship between professional identity and instructional practices.	69 STEM faculty at a research-intensive university	Mixed	USA	Biology, chemistry, physics/astronomy, mathematics/statistics, computer science, engineering, environmental science, and social sciences	Lattuca and Pollard's Model of Faculty Decision-Making	Yes	EBIPs studied included think-pair-share, just-in-time teaching, case studies, SCALE-UP, collaborative learning, cooperative learning, and peer instruction.
Lane, A. K., Skvoretz, J., Ziker, J. P., Couch, B. A., Earl, B., Lewis, J. E., ... & Stains, M.	2019	To explore how faculty social networks and peer influence within biology and chemistry departments at three universities impact their knowledge and use of evidence-based instructional practices (EBIPs)	142 faculty from biology and chemistry departments at three large public research universities.	Quantitative	USA	Biology and Chemistry	Peer Influence Models based on the Social Network Theory literature	Yes	EBIPs analyzed included: Think-pair-share, peer instruction, cooperative learning, team-based learning
Borda, E., Schumacher, E., Hanley, D., Geary, E., Warren, S., Ipsen, C., & Stredicke, L.	2020	To examine the initial implementation of active learning strategies by STEM faculty participating in a multi-institutional professional development program and to explore faculty and student perceptions of these practices	In total, 324 STEM faculty from one regional university of two community colleges	Mixed	USA	Biology, Chemistry, Environmental Science, Geology, Mathematics, Physics, Astronomy, and Computer Science	1) Constructivism 2) Diffusion of Innovations Model (used for design faculty development program) 3) Formative assessment	Yes	ABCD voting cards (low-tech clickers), structured small-group discussions, tutorials and worksheets designed to develop students' conceptual understanding, use of whiteboards for student idea representation.
Teasdale, R., Ryker, K., Viskupic, K., Czajka, C. D., & Manduca, C.	2020	To evaluate the impact of using InTeGrate (ITG) curriculum materials on the teaching practices of STEM instructors, specifically their use of student-centered instructional strategies	287 STEM instructors & 345 classroom observations	Quantitative	USA	Geoscience and related disciplines, with some non-geoscience courses (e.g., nursing, philosophy)	Interconnected Model of Professional Growth (Clarke & Hollingsworth, 2002)	Yes	ITG materials embed active learning strategies such as: Group discussions, problem-solving, collaborative learning, use of formative and summative assessments

O'Leary, S. E., Shapiro, C., Toma, S., Sayson, H. W., Johnson, T., & Sork, V. L.	2020	To evaluate the impact of a multiday, off-campus immersion workshop on STEM faculty's knowledge, attitudes, and practices related to culturally responsive and inclusive teaching	115 participants (STEM faculty with a small number of staff from UCLA) across three cohorts (2015, 2016, 2017)	Mixed	USA	Broad STEM fields, including life and physical sciences	Culturally Responsive Pedagogy Framework (Gay, 2018)	Yes	Inclusive teaching practices emphasized: Active learning. Collaborative learning. Growth mindset integration. Addressing microaggressions and stereotype threat in classroom interactions.
Corrales, A., Goldberg, F., Price, E., & Turpen, C.	2020	To explore how participation in a Faculty Online Learning Community (FOLC) supports a faculty member's reflection and persistence in implementing research-based instructional strategies (RBIS)	One focal faculty member ("Leslie," pseudonym), part of a larger group of 48 FOLC participants	Qualitative	USA	Physics and Physical Science courses (for pre-service elementary teachers and general education students)	Rodgers' Reflection Framework	Yes	Next Gen PET curriculum embedded strategies such as: Group work and whole-class discussions. Inquiry-based learning (e.g., supporting claims with evidence). Collaborative sense-making through scientific practices.
Erdmann, R., Miller, K., & Stains, M.	2020	To investigate how postsecondary STEM instructors plan and reflect on their teaching practices for a week of instruction and identify factors influencing planned revisions	42 STEM faculty from R1 public university	Mixed	USA	Biology, Chemistry, Mathematics, Physics, and related STEM fields	Reflective Practice Framework (Schön, 1983)	No	Clicker questions (used more for engagement than assessment). Group discussions. Just-in-Time Teaching (JiTT) in some cases.
Sachmpazidi, D., Olmstead, A., Thompson, A. N., Henderson, C., & Beach, A.	2021	To identify and describe the specific team processes and emergent states that shape the effectiveness of instructional change teams in undergraduate STEM education	23 team members from 4 instructional change teams across 3 U.S. research-intensive institutions	Mixed	USA	Physics, Biology, Material Science, and Engineering	Input-Process-Output (I-P-O) Model	No	Integration of active learning elements into course curricula (e.g., group discussions, flipped classrooms)
Lau, A. C., Martin, M., Corrales, A., Turpen, C., Goldberg, F., & Price, E.	2021	To develop and validate the Taxonomy of Opportunities to Learn (TxOTL) as a framework for analyzing the learning potential and content of conversations in Faculty Online Learning Communities (FOLCs)	Faculty implementing 1) the Next Generation Physical Science and Everyday Thinking curriculum and 2) the New Faculty Workshop FOLC	Qualitative	USA	Physics, Astronomy, and related STEM disciplines	Opportunities to learn	Not sure	Strategies discussed in FOLC meetings included: Guided-inquiry pedagogy (central to the NextGenPET curriculum). Peer discussions and small-group activities. Interactive engagement using classroom tools like clickers.
Zhao, F. F., Chau, L., & Schuchardt, A.	2021	To examine how instructors provide sensemaking opportunities when teaching mathematical equations in undergraduate biology, focusing on types and organization of	4 biology instructors teaching population growth using	Qualitative	USA	Biology	Sci-Math Sensemaking Framework (Zhao & Schuchardt, 2021)	No	Group work and collaborative problem-solving (e.g., building equations in

		sensemaking opportunities across instructors	mathematical equation						teams) and student presentations of solutions.
Price, E., Lau, A. C., Goldberg, F., Turpen, C., Smith, P. S., Dancy, M., & Robinson, S.	2021	To examine how a Faculty Online Learning Community (FOLC) supports STEM faculty in adopting and implementing the Next Generation Physical Science and Everyday Thinking (Next Gen PET) curriculum, a guided-inquiry curriculum	50 STEM faculty in the FOLC, with demographics reported from 42 respondents.	Mixed	USA	Primarily physics, physical science, and related STEM disciplines for pre-service teachers and general education students	Propagation Paradigm	Yes	Strategies embedded in the Next Gen PET curriculum include: Guided-inquiry learning, student-led discussions and evidence-based reasoning, collaborative problem-solving.
McAlpin, J. D., Ziker, J. P., Skvoretz, J., Couch, B. A., Earl, B., Feola, S., ... & Lewis, J. E.	2022	To develop and validate the Cooperative Adoption Factors Instrument (CAFI), which measures faculty perceptions of factors affecting the adoption of evidence-based instructional practices (EBIPs) in STEM departments	296 STEM faculty from three large U.S. public research universities	Quantitative	USA	Biology, Chemistry, Earth Sciences, Mathematics, and Physics	CACAO Model of Change (Dormant, 2011)	Yes	The study focuses broadly on evidence-based instructional practices (EBIPs), which include: active learning, peer instruction, collaborative learning
Donham, C., Barron, H. A., Alkhouri, J. S., Changaran Kumarath, M., Alejandro, W., Menke, E., & Kranzfelder, P.	2022	To investigate the perceived supports and barriers experienced by STEM instructors and students during the transition to Emergency Remote Teaching (ERT) at a research-intensive, Minority-Serving Institution (MSI).	31 STEM faculty & 69 undergraduate students in STEM courses, , primarily in biology, chemistry, and physics at the University of California, Merced	Mixed	USA	Biology, Chemistry, Engineering, Mathematics, and Physics	1) Community of Inquiry Framework 2) Scaffolding Theory	No	Strategies adapted to ERT included: Use of breakout rooms for group discussions, integration of formative assessments via online platforms, synchronous online lectures with real-time Q&A.
Lane, A. K., Earl, B., Feola, S., Lewis, J. E., McAlpin, J. D., Mertens, K., ... & Prevost, L. B.	2022	To explore the context and content of teaching-related conversations between science faculty to better understand how these discussions promote the dissemination of evidence-based instructional practices (EBIPs)	19 STEM faculty identified as high users of EBIPs	Qualitative	USA	Biology, Chemistry, and Geoscience	1) Knowledge sharing framework adapted from Ipe (2003); 2) Social network theory (for developing the interview protocol)	Yes	The study indirectly references active learning strategies discussed among faculty, such as: Inquiry-based activities, group work, flipped classroom approaches.
Biswas, S., Benabentos, R., Brewe, E., Potvin, G., Edward, J.,	2022	To evaluate the impacts of the Collaborative for Institutionalizing Scientific Learning (CISL) program on faculty adoption of evidence-based teaching practices (EBIPs), student performance, and	41 STEM faculty supported by the CISL program (2011–2019) & 28 courses	Mixed	USA	Biology, Chemistry, Physics, and Mathematics	N/A	N/A	Strategies included: Flipped classrooms, clickers for real-time feedback, group work facilitated by Learning Assistants, pre-class assignments and reflective activities.

Kravec, M., & Kramer, L.		institutional change at a large Hispanic-Serving Institution (HSI)							
Yik, B. J., Raker, J. R., Apkarian, N., Stains, M., Henderson, C., Dancy, M. H., & Johnson, E.	2022	To evaluate the impacts of the Collaborative for Institutionalizing Scientific Learning (CISL) program on faculty adoption of evidence-based teaching practices (EBIPs), student performance, and institutional change at a large Hispanic-Serving Institution (HSI)	2382 instructors teaching introductory STEM gateway courses	Quantitative	USA	Chemistry, Mathematics, and Physics	Teacher-centered systemic reform model	Yes	“Percent time lecturing” as a proxy for active learning (While specific strategies like group work are discussed in relation to classroom setup, the focus is on overall time spent not lecturing)
Denaro, K., Kranzfelder, P., Owens, M. T., Sato, B., Zuckerman, A. L., Hardesty, R. A., ... & Lo, S. M.	2022	To examine the extent to which tenure-track teaching faculty (Teaching Professors or Professors of Teaching [TP/PoTs]) adopt active learning compared to tenure-track research faculty and non-tenure-track lecturers in undergraduate STEM classrooms.	125 STEM undergraduate courses across three campuses in the University of California system	Quantitative	USA	Biology, Physical Sciences, Engineering, and Information & Computer Sciences	N/A	N/A	Strategies included collaborative group work, clicker questions, and guided discussions, though not detailed beyond COPUS categories (e.g., “Student.Working”)
Shultz, M., Nissen, J., Close, E., & Van Dusen, B.	2022	To explore how STEM faculty’s epistemological beliefs influence their decisions to implement culturally relevant pedagogy (CRP) at Hispanic-Serving Institutions (HSIs)	40 undergraduate STEM instructors from 27 HSIs	Qualitative	USA	Biology (17), Chemistry (7), Physics (6), Mathematics (10)	Practical Rationality Framework	Yes	Strategies were discussed indirectly through CRP-related practices, including: Group discussions, collaborative assignments, context-specific applications of STEM concepts (e.g., addressing community health issues in biology).
Gehrtz, J., Brantner, M., & Andrews, T. C.	2022	To investigate how undergraduate STEM instructors use student thinking to inform their teaching, focusing on how they access, interpret, and respond to student thinking during instruction	8 undergraduate STEM instructors from a single research-intensive university	Mixed	USA	Biology, Chemistry, Physics, and Mathematics	1) Teacher Noticing Framework; 2) Responsive Teaching Framework; 3) Pedagogical Content Knowledge	No	Accessing Student Thinking: Clicker questions, small-group discussions, and worksheets. Interpreting and Responding: Tailoring instruction based on student responses, revisiting content, and adjusting pacing.
Viskupic, K., Earl, B., & Shadle, S. E.	2022	To adapt and apply the CACAO Model of Change to a higher education STEM education reform project, focusing on its utility in promoting institutional changes in	155 STEM from 12 departments at Boise State University	Mixed	USA	Biology, Chemistry, Physics, and Mathematics	CACAO Model of Change (Dormant, 2011)	Yes	Strategies included: Think-pair-share, clickers for real-time student feedback, Process-Oriented Guided Inquiry Learning (POGIL), Team-Based Learning (TBL).

		teaching practices, departmental culture, and organizational policies							
Jackson, M. A., Moon, S., Doherty, J. H., & Wenderoth, M. P.	2022	To investigate how participation in the Consortium for the Advancement of Undergraduate STEM Education (CAUSE) program influences the adoption and implementation of specific evidence-based teaching practices (PORTAAL practices) over time	47 STEM faculty from 7 departments & 42 paired course at a research-intensive university in the Northwest	Mixed	USA	Biology, Chemistry, Computer Science, Mathematics, Physics, Psychology, and Public Health	1) Interconnected Model of Professional Growth; 2) Best practices for faculty development; 3) Systems thinking University as an ecosystem	Yes	The study focused on 14 PORTAAL practices, including: Prompting students to explain logic, randomly calling on students, small group work, high Bloom's activities, positive feedback.
Weston, T. J., Laursen, S. L., & Hayward, C. N.	2023	To explore the effectiveness of segmented and holistic observation protocols (TAMI-OP and RTOP) in characterizing teaching practices and measuring instructional change among STEM faculty	74 mathematics instructors & 790 classes observed	Quantitative	USA	Mathematics	N/A	N/A	The study focuses broadly on instructional practices rather than specific active learning strategies. Profiles included: 1) Interactive Lecture and Review: Mix of lecture and group work; 2) Group Work: Class dominated by collaborative problem-solving; 3) Student Presentation: Students actively presenting and discussing material.
Rozhenkova, V., Snow, L., Sato, B. K., Lo, S. M., & Buswell, N. T.	2023	To explore and compare the conceptions of teaching and learning, instructional practices, and learning environments between STEM Professors of Teaching (PoTs) and Research Professors (RPs) at a minority-serving, research-intensive university	10 STEM faculty from a single department at a U.S. research-intensive, minority-serving institution	Qualitative	USA	Not specific	1) Conceptions of Teaching and Learning Framework 2) Learner-Centered Teaching Principles	No	Active learning strategies mentioned include: Group work, student presentations, collaborative problem-solving, interactive engagement in lectures.
Lau, A. C., Henderson, C., Stains, M., Dancy, M., Merino, C., Apkarian, N., Raker, J. R., & Johnson, E.	2024	To identify and characterize the features of STEM departments that have successfully integrated high levels of active learning in introductory courses, with the aim of developing a model to inform departmental transformation efforts	27 instructors from 16 STEM departments identified as high-use of active learning	Qualitative	USA	Chemistry, Mathematics, and Physics	Four Frames Model (Reinholz & Apkarian, 2018) but mainly based on grounded theory	Yes	Active learning strategies used in departments included: Collaborative group work, inquiry-based activities, flipped classrooms, peer instruction using clickers.

Challenges and strategies

The reviewed literature identifies several challenges faced by STEM instructors when implementing active learning strategies. One common barrier is the significant time and effort required to redesign courses and assessments. Czajka and McConnell [14] highlight how these time constraints can hinder the adaptation of unique course content. Similarly, Borda et al. [8] report that instructors frequently cite workload demands as a major obstacle to integrating active learning practices. Institutional resistance further complicates these efforts, with many departments emphasizing research over teaching. Shadle et al. [60] and Denaro et al. [16] both note the lack of incentives for teaching innovation, particularly in research-intensive settings. Classroom infrastructure is another hurdle, as Knaub et al. [33] observe that traditional layouts often fail to support the requirements of active learning. Additionally, students accustomed to lecture-based teaching methods frequently resist active learning approaches, as described by Tharayil et al. [67].

Instructors also face psychological and cultural challenges. Anxiety about relinquishing control in a student-centered classroom, as noted by Czajka and McConnell [14], and skepticism from colleagues resistant to change are common issues. Cultural norms in certain disciplines, such as physical sciences, further exacerbate resistance to non-traditional teaching methods, as reported by Denaro et al. [16]. A lack of tailored professional development opportunities and resources also presents significant barriers, particularly for instructors with limited experience in active learning. Price et al. [50] and Shadle et al. [60] emphasize the steep learning curves faced by faculty new to these methods.

To address these challenges, effective strategies have emerged from the literature. Professional development programs, such as the faculty learning communities described by Tinnell et al. [70], provide instructors with structured support, including workshops, mentoring, and opportunities for collaborative discussions. Communities of practice, as highlighted by Tomkin et al. [71], foster peer support and the sharing of best practices, creating a collaborative environment conducive to sustained instructional change. Transparent communication with students about the purpose and benefits of active learning is another essential strategy. Tharayil et al. [67] suggest that proactive explanations and incremental adoption of new techniques help reduce student resistance and build confidence among both students and faculty.

Institutional support is crucial for sustaining active learning practices. Departments that foster collaborative teaching cultures, provide funding for classroom redesign, and offer flexible teaching spaces report higher rates of active learning adoption, as noted by Lau et al. [38]. Incorporating teaching excellence into tenure and promotion criteria serves as a strong motivator for faculty to engage in instructional innovation, as Shadle et al. [60] point out. Koretsky et al. [34] demonstrate how tailored resources, such as active learning classrooms, facilitate successful implementation.

Finally, reflective practices and iterative experimentation are instrumental in refining active learning strategies. Gehrtz et al. [22] show how tools like clickers and group discussions help instructors gather real-time feedback and adapt their approaches. Reflective practices, as described by Sachmpazidi et al. [55], enable faculty to evaluate and improve their teaching over time. By addressing individual, departmental, and institutional barriers, these strategies collectively support the effective implementation of active learning in STEM education.

Conclusion

Although focused on a single journal, this literature review highlights the challenges and strategies experienced by STEM instructors, especially engineering educators, when implementing active learning. Engineering courses often involve a blend of theoretical analysis, practical design work, and team projects, making them prime contexts for understanding how to integrate active, student-centered approaches across diverse instructional modes. Furthermore, engineering students frequently take foundational courses in mathematics, physics, chemistry, and other scientific disciplines, where active learning strategies are increasingly encouraged but still face barriers to widespread adoption. Therefore, understanding the challenges and strategies encountered across the broader STEM landscape is highly relevant to engineering education, as these foundational courses directly shape engineering students' learning experiences, critical thinking skills, and problem-solving abilities.

The findings also elucidate barriers (e.g., limited incentives, logistical hurdles, student and colleague resistance) and point to actionable strategies (e.g., faculty learning communities, transparent student communication, institutional support) that can improve teaching effectiveness. Many of these strategies are particularly pertinent to engineering instructors, who must bridge conceptual understanding with real-world application, often within team-based, project-driven environments.

From a faculty development standpoint, these results reinforce the critical role that structured initiatives and sustained mentoring play in achieving broad adoption of evidence-based teaching. Faculty Development Division members can leverage the insights presented here to design workshops or create learning communities tailored to engineering educators' specific concerns, balancing time constraints with disciplinary demands. In line with recommendations from major funding agencies and change-theory frameworks, these interventions can address not only what is being taught but also how it is being taught. This is an undertaking that often proves more demanding but ultimately leads to transformative impacts on student learning outcomes.

Despite the comprehensive hand-search approach, this review is not without limitations. Studies from international contexts, community colleges, or underrepresented voices in STEM may be underrepresented. Moreover, reliance on publications in a single journal risks perpetuating biases. Future reviews spanning multiple publication venues and broader educational settings could enhance the inclusivity and generalizability of the findings.

Overall, this work underscores that while integrating active learning can be challenging in any STEM field, engineering education presents an especially instructive case due to its strong connections to real-world problem-solving and its intersection with multiple scientific and mathematical domains.

Acknowledgement

I greatly appreciate Professor Pamela Moss and Emily Seeber, who guided me in accomplishing this course final project.

References

An asterisk (*) indicating included articles

[1] Abrahams. (2010). Technology adoption in higher education: A framework for identifying and prioritising issues and barriers to adoption of instructional technology. *Journal of Applied Research in Higher Education*, *2*(2), 34-49.

[2] Andrews, T. C., & Lemons, P. P. (2015). It's personal: Biology instructors prioritize personal evidence over empirical evidence in teaching decisions. *CBE—Life Sciences Education, 14*(1), 1-18.

[3] *Auerbach, A. J. J., & Andrews, T. C. (2018). Pedagogical knowledge for active-learning instruction in large undergraduate biology courses: a large-scale qualitative investigation of instructor thinking. International journal of STEM education, 5(1), 1-25.

[4] *Bathgate, M. E., Aragón, O. R., Cavanagh, A. J., Waterhouse, J. K., Frederick, J., & Graham, M. J. (2019). Perceived supports and evidence-based teaching in college STEM. *International Journal of STEM Education, 6*(1), 1–14.

[5] *Biswas, S., Benabentos, R., Brewe, E., Potvin, G., Edward, J., Kravec, M., & Kramer, L. (2022). Institutionalizing evidence-based STEM reform through faculty professional development and support structures. International Journal of STEM Education, 9(1), 1-23.

[6] Boelens, R., De Wever, B., & Voet, M. (2017). Four key challenges to the design of blended learning: A systematic literature review. *Educational Research Review*, *22*, 1-18.

[7] Bonwell, C. C., & Eison, J. A. (1991). *Active learning: Creating excitement in the classroom. 1991 ASHE-ERIC higher education reports*. ERIC Clearinghouse on Higher Education, The George Washington University, One Dupont Circle, Suite 630, Washington, DC 20036-1183.

[8] *Borda, E., Schumacher, E., Hanley, D., Geary, E., Warren, S., Ipsen, C., & Stredicke, L. (2020). Initial implementation of active learning strategies in large, lecture STEM courses: Lessons learned from a multi-institutional, interdisciplinary STEM faculty development program. *International Journal of STEM Education, 7*(1), 1-18.

[9] Carroll, L. J., Reeping, D., Finelli, C. J., Prince, M. J., Husman, J., Graham, M., & Borrego, M. J. (2023). Barriers instructors experience in adopting active learning: Instrument development. *Journal of Engineering Education*.

[10] Chamo, N., Biberman-Shalev, L., & Broza, O. (2023). 'Nice to Meet You Again': When heutagogy met blended learning in teacher education, post-pandemic era. *Education Sciences*, *13*(6), 536.

[11] Chen, B., Bastedo, K., & Howard, W. (2018). Exploring design elements for online STEM courses: Active learning, engagement & assessment design. *Online Learning, 22*(2), 59-75.

[12] *Corrales, A., Goldberg, F., Price, E., & Turpen, C. **(2020).** Faculty persistence with research-based instructional strategies: A case study of participation in a faculty online learning community. *International Journal of STEM Education, 7*(1), 1–15.

[13] Cuban, L. (1999). *How scholars trumped teachers: Change without reform in university curriculum, teaching, and research, 1890-1990*. Teachers College Press.

[14] *Czajka, C. D., & McConnell, D. (2016). Situated instructional coaching: A case study of faculty professional development. *International Journal of STEM Education, 3*(1), 1–14.

[15] Dantas, A. M., & Kemm, R. E. (2008). A blended approach to active learning in a physiology laboratory-based subject facilitated by an e-learning component. *Advances in physiology education*, *32*(1), 65-75.
[16] *Denaro, K., Kranzfelder, P., Owens, M. T., Sato, B., Zuckerman, A. L., Hardesty, R. A., ... & Lo, S. M. (2022). Predicting implementation of active learning by tenure-track teaching faculty using robust cluster analysis. International journal of STEM education, 9(1), 49.
[17] *Donham, C., Barron, H. A., Alkhouri, J. S., Changaran Kumarath, M., Alejandro, W., Menke, E., & Kranzfelder, P. (2022). I will teach you here or there, I will try to teach you anywhere: Perceived supports and barriers for emergency remote teaching during the COVID-19 pandemic. *International Journal of STEM Education, 9*(1), 19.
[18] *Erdmann, R., Miller, K., & Stains, M. (2020). Exploring STEM postsecondary instructors' accounts of instructional planning and revisions. *International Journal of STEM Education, 7*(1), 1–17.
[19] Finelli, C. J., Daly, S. R., & Richardson, K. M. (2014). Bridging the research-to-practice gap: Designing an institutional change plan using local evidence. *Journal of Engineering Education, 103*(2), 331-361.
[20] *Foote, K. T., Neumeyer, X., Henderson, C., Dancy, M. H., & Beichner, R. J. (2014). Diffusion of research-based instructional strategies: The case of SCALE-UP. *International Journal of STEM Education, 1*(1), 1–18.
[21] Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences, 111*(23), 8410–8415.
[22] *Gehrtz, J., Brantner, M., & Andrews, T. C. (2022). How are undergraduate STEM instructors leveraging student thinking? *International Journal of STEM Education, 9*(1), 1–20.
[23] Gough, D., Oliver, S., & Thomas, J. (2017). *An introduction to systematic reviews*. SAGE.
[24] Guo, Y., Liu, H., Hao, A., Liu, S., Zhang, X., & Liu, H. (2022). Blended learning model via small private online course improves active learning and academic performance of embryology. *Clinical Anatomy*, *35*(2), 211-221.
[25] Haak, D. C., HilleRisLambers, J., Pitre, E., & Freeman, S. (2011). Increased structure and active learning reduce the achievement gap in introductory biology. *Science*, *332*(6034), 1213-1216.
[26] Hall, S. R., Waitz, I., Brodeur, D. R., Soderholm, D. H., & Nasr, R. (2002, November). Adoption of active learning in a lecture-based engineering class. In *32nd Annual frontiers in education* (Vol. 1, pp. T2A 9-T2A15). IEEE.
[27] *Hayward, C. N., & Laursen, S. L. (2018). Supporting instructional change in mathematics: Using social network analysis to understand online support processes following professional development workshops. International Journal of STEM Education, 5, 1-19.
[28] Hopewell, S., Clarke, M. J., Lefebvre, C., & Scherer, R. W. (2007). Handsearching versus electronic searching to identify reports of randomized trials. *Cochrane Database of Systematic Reviews*, (2).
[29] Huang, J. (2020). Successes and challenges: Online teaching and learning of chemistry in higher education in China in the time of COVID-19. *Journal of Chemical Education, 97*(9), 2810-2814.
[30] *Jackson, M. A., Moon, S., Doherty, J. H., & Wenderoth, M. P. (2022). Which evidence-based teaching practices change over time? Results from a university-wide

STEM faculty development program. *International Journal of STEM Education, 9*(1), 1–15.

[31] *Johnson, E., Keller, R., Peterson, V., & Fukawa-Connelly, T. (2019). Individual and situational factors related to undergraduate mathematics instruction. International Journal of STEM Education, 6, 1-24. Keane, T., Linden, T., Hernandez-Martinez, P., & Molnar, A. (2022). University students' experiences and reflections of technology in their transition to online learning during the global pandemic. *Education Sciences, 12*(7), 453.

[32] Khan, A., Egbue, O., Palkie, B., & Madden, J. (2017). Active learning: Engaging students to maximize learning in an online course. *Electronic Journal of e-learning, 15*(2), 107-115.

[33] *Knaub, A. V., Foote, K. T., Henderson, C., Dancy, M., & Beichner, R. J. (2016). Get a room: The role of classroom space in sustained implementation of studio style instruction. *International Journal of STEM Education, 3*(1), 1–22.

[34] *Koretsky, M., Keeler, J., Ivanovitch, J., & Cao, Y. (2018). The role of pedagogical tools in active learning: A case for sense-making. *International Journal of STEM Education, 5*(1), 1–20.

[35] *Lane, A. K., Earl, B., Feola, S., Lewis, J. E., McAlpin, J. D., Mertens, K., ... & Prevost, L. B. (2022). Context and content of teaching conversations: exploring how to promote sharing of innovative teaching knowledge between science faculty. International Journal of STEM Education, 9(1), 1-16.

[36] *Lane, A. K., Skvoretz, J., Ziker, J. P., Couch, B. A., Earl, B., Lewis, J. E., ... & Stains, M. (2019). Investigating how faculty social networks and peer influence relate to knowledge and use of evidence-based teaching practices. International Journal of STEM Education, 6(1), 1-14.

[37] *Landrum, R. E., Viskupic, K., Shadle, S. E., & Bullock, D. (2017). Assessing the STEM landscape: the current instructional climate survey and the evidence-based instructional practices adoption scale. International Journal of STEM Education, 4(1), 25–35.

[38] *Lau, A. C., Henderson, C., Stains, M., Dancy, M., Merino, C., Apkarian, N., Raker, J. R., & Johnson, E. (2024). Characteristics of departments with high-use of active learning in introductory STEM courses: Implications for departmental transformation. *International Journal of STEM Education, 11*(1), 1–21.

[39] *Lau, A. C., Martin, M., Corrales, A., Turpen, C., Goldberg, F., & Price, E. (2021). The Taxonomy of Opportunities to Learn (TxOTL): A tool for understanding the learning potential and substance of interactions in faculty (online) learning community meetings. *International Journal of STEM Education, 8*(1), 1–24.

[40] Luburić, N., Slivka, J., Sladić, G., & Milosavljević, G. (2021). The challenges of migrating an active learning classroom online in a crisis. *Computer Applications in Engineering Education, 29*(6), 1617-1641.

[41] *Lund, T. J., & Stains, M. (2015). The importance of context: an exploration of factors influencing the adoption of student-centered teaching among chemistry, biology, and physics faculty. International Journal of STEM Education, 2, 13.

[42] *McAlpin, J. D., Ziker, J. P., Skvoretz, J., Couch, B. A., Earl, B., Feola, S., ... & Lewis, J. E. (2022). Development of the Cooperative Adoption Factors Instrument to measure factors associated with instructional practice in the context of institutional change. International Journal of STEM Education, 9(1), 48.

[43] Nelson, J. K., Rosenberg, J., Fernández, K., & Shank, J. (2021, July). *Where's my whiteboard?: The challenge of moving active-learning mathematics classes online.* In 2021 ASEE Virtual Annual Conference Content Access.

[44] Nguyen, K. A., Borrego, M., Finelli, C. J., DeMonbrun, M., Crockett, C., Tharayil, S., Shekhar, P., Waters, C., & Rosenberg, R. (2021). Instructor strategies to aid implementation of active learning: A systematic literature review. *International Journal of STEM Education, 8*(1), 1-18.

[45] *Olmstead, A., Beach, A., & Henderson, C. (2019). Supporting improvements to undergraduate STEM instruction: An emerging model for understanding instructional change teams. *International Journal of STEM Education, 6*, 1–15.

[46] O'Dea, X.C., & Stern, J. (2022). Virtually the same?: Online higher education in the post Covid-19 era. *British Journal of educational technology, 53*(3), 437.

[47] *O'Leary, S. E., Shapiro, C., Toma, S., Sayson, H. W., Johnson, T., & Sork, V. L. (2020). Creating inclusive classrooms by engaging STEM faculty in culturally responsive teaching workshops. *International Journal of STEM Education, 7*(1), 1–15.

[48] Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *bmj*, *372*.

[49] *Pelch, M. A., & McConnell, D. A. (2016). Challenging instructors to change: A mixed methods investigation on the effects of material development on the pedagogical beliefs of geoscience instructors. *International Journal of STEM Education, 3*(5), 1–18.

[50] Porter, W. W., & Graham, C. R. (2016). Institutional drivers and barriers to faculty adoption of blended learning in higher education. *British Journal of Educational Technology*, *47*(4), 748-762.

[51] *Price, E., Lau, A. C., Goldberg, F., Turpen, C., Smith, P. S., Dancy, M., & Robinson, S. (2021). Analyzing a faculty online learning community as a mechanism for supporting faculty implementation of a guided-inquiry curriculum. *International Journal of STEM Education, 8*(1), 1–26.

[52] *Quardokus Fisher, K., Sitomer, A., & Koretsky, M. (2019). Using social network analysis to develop relational expertise for an instructional change initiative. *International Journal of STEM Education, 6*(1), 1–12.

[53] Reid, P. (2014). Categories for barriers to adoption of instructional technologies. *Education and Information Technologies*, *19*, 383-407.

[54] Reinholz, D. L., White, I., & Andrews, T. (2021). Change theory in STEM higher education: a systematic review. *International Journal of STEM Education*, *8*(1), 1-22.

[55] *Rozhenkova, V., Snow, L., Sato, B. K., Lo, S. M., & Buswell, N. T. (2023). Limited or complete? Teaching and learning conceptions and instructional environments fostered by STEM teaching versus research faculty. *International Journal of STEM Education, 10*(1), 1–20.

[56] *Sachmpazidi, D., Olmstead, A., Thompson, A. N., Henderson, C., & Beach, A. (2021). Team-based instructional change in undergraduate STEM: characterizing effective faculty collaboration. International Journal of STEM Education, 8(1), 1-23.

[57] *Scanlon, E., Zamarripa Roman, B., Ibadlit, E., & Chini, J. J. (2019). A method for analyzing instructors' purposeful modifications to research-based instructional strategies. International Journal of STEM Education, 6, 1-18.

[58] Schön, D.A. (1983). *The reflective practitioner: How professionals think in action*. Basic Books.

[59] Schucan Bird, K. L., Newman, M., Hargreaves, K., & Sawtell, M. (2015). Workplace-based learning for undergraduate and pre-registration healthcare professionals: a systematic map of the UK research literature 2003-2013.

[60] *Shadle, S. E., Marker, A., & Earl, B. (2017). Faculty drivers and barriers: Laying the groundwork for undergraduate STEM education reform in academic departments. International Journal of STEM Education, 4(1), 1-13.

[61] *Shultz, M., Nissen, J., Close, E., & Van Dusen, B. (2022). The role of epistemological beliefs in STEM faculty's decisions to use culturally relevant pedagogy at Hispanic-Serving Institutions. *International Journal of STEM Education, 9*(1), 1–22.
[62] Singhal, R., Kumar, A., Singh, H., Fuller, S., & Gill, S. S. (2021). Digital device-based active learning approach using virtual community classroom during the COVID-19 pandemic. *Computer Applications in Engineering Education, 29*(5), 1007-1033.
[63] SpringerOpen. (n.d.). International Journal of STEM Education: About. Retrieved November 24, 2023, from https://stemeducationjournal.springeropen.com/about
[64] Stains, M., Harshman, J., Barker, M. K., Chasteen, S. V., Cole, R., DeChenne-Peters, S. E., ... & Young, A. M. (2018). Anatomy of STEM teaching in North American universities. *Science, 359*(6383), 1468-1470.
[65] *Sturtevant, H., & Wheeler, L. (2019). The STEM faculty instructional barriers and identity survey (FIBIS): Development and exploratory results. International Journal of STEM Education, 6, 1-22.
[66] *Teasdale, R., Ryker, K., Viskupic, K., Czajka, C. D., & Manduca, C. (2020). Transforming education with community-developed teaching materials: evidence from direct observations of STEM college classrooms. International Journal of STEM Education, 7, 1-22.
[67] *Tharayil, S., Borrego, M., Prince, M., Nguyen, K. A., Shekhar, P., Finelli, C. J., & Waters, C. (2018). Strategies to mitigate student resistance to active learning. International Journal of STEM Education, 5, 1-16.
[68] Theobald, E. J., Hill, M. J., Tran, E., Agrawal, S., Arroyo, E. N., Behling, S., Chambwe, N., Cintrón, D. L., Cooper, J. D., Dunster, G., Grummer, J. A., Hennessey, K., Hsiao, J., Iranon, N., Jones, L., Jordt, H., Keller, M., Lacey, M. E., Littlefield, C. E., & Freeman, S. (2020). Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. *Proceedings of the National Academy of Sciences of the United States of America, 117*(12), 6476-6483
[69] *Thompson, A. N., Talbot, R. M., Doughty, L., Huvard, H., Le, P., Hartley, L., & Boyer, J. (2020). Development and application of the action taxonomy for learning assistants (ATLAs). *International Journal of STEM education*, 7, 1-14.
[70] *Tinnell, T. L., Ralston, P. A., Tretter, T. R., & Mills, M. E. (2019). Sustaining pedagogical change via faculty learning community. *International Journal of STEM Education, 6*(1), 1-16.
[71] *Tomkin, J. H., Beilstein, S. O., Morphew, J. W., & Herman, G. L. (2019). Evidence that communities of practice are associated with active learning in large STEM lectures. International Journal of STEM Education, 6, 1-15.
[72] Venton, B.J., & Pompano, R.R. (2021). Strategies for enhancing remote student engagement through active learning. *Analytical and Bioanalytical Chemistry, 413*, 1507-1512.
[73] *Viskupic, K., Earl, B., & Shadle, S. E. (2022). Adapting the CACAO model to support higher education STEM teaching reform. *International Journal of STEM Education, 9*(1), 1–20.
[74] Wang, Q., & Huang, Q. (2023). Engaging Online Learners in Blended Synchronous Learning: A systematic literature review. *IEEE Transactions on Learning Technologies*.
[75] *Weston, T. J., Laursen, S. L., & Hayward, C. N. (2023). Measures of success: Characterizing teaching and teaching change with segmented and holistic observation data. *International Journal of STEM Education, 10*(1), 24.
[76] Wilson, B. M., Pollock, P. H., & Hamann, K. (2007). Does active learning enhance learner outcomes? Evidence from discussion participation in online classes. *Journal of Political Science Education, 3*(2), 131-142.

[77] *Yik, B. J., Raker, J. R., Apkarian, N., Stains, M., Henderson, C., Dancy, M. H., & Johnson, E. (2022). Evaluating the impact of malleable factors on percent time lecturing in gateway chemistry, mathematics, and physics courses. International Journal of STEM Education, 9(1), 15.

[78] Zhao, Y., & Watterston, J. (2021). The changes we need: Education post COVID-19. *Journal of Educational Change, 22*(1), 3-12.

[79] Zimmerman, J. (2020). *The amateur hour: A history of college teaching in America*. Johns Hopkins University Press.

[80] Henderson, C., Beach, A., & Finkelstein, N. (2011). Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature. *Journal of research in science teaching, 48*(8), 952-984.

[81] Reinholz, D. L., & Andrews, T. C. (2020). Change theory and theory of change: what's the difference anyway?. *International Journal of STEM Education*, *7*, 1-12.

[82] Schucan Bird, K. L., Newman, M., Hargreaves, K., & Sawtell, M. (2015). *Workplace-based learning for undergraduate and pre-registration healthcare professionals: A systematic map of the UK research literature 2003-2013*. EPPI-Centre, Social Science Research Unit, UCL Institute of Education, University College London.

[83] Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*, n71.