International Journal of STEM Education

RESEARCH

Open Access

Characteristics of departments with high-use of active learning in introductory STEM courses: implications for departmental transformation

Alexandra C. Lau[1*], Charles Henderson[2], Marilyne Stains[3], Melissa Dancy[4], Christian Merino[2], Naneh Apkarian[5], Jeffrey R. Raker[6] and Estrella Johnson[7]

Abstract

Background It is well established in the literature that active learning instruction in introductory STEM courses results in many desired student outcomes. Yet, regular use of high-quality active learning is not the norm in many STEM departments. Using results of a national survey, we identified 16 departments where multiple instructors reported using high levels of active learning in their introductory chemistry, mathematics, or physics courses. We conducted interviews with 27 instructors in these 16 departments to better understand the characteristics of such departments.

Results Using grounded theory methodology, we developed a model that highlights relevant characteristics of departments with high use of active learning instruction in their introductory courses. According to this model, there are four main, interconnected characteristics of such departments: motivated people, knowledge about active learning, opportunities, and cultures and structures that support active learning. These departments have one or more people who are motivated to promote the use of active learning. These motivated people have knowledge about active learning as well as access to opportunities to promote the use of active learning. Finally, these departments have cultures and structures that support the use of active learning. In these departments, there is a positive feedback loop that works iteratively over time, where motivated people shape cultures/structures and these cultures/structures in turn increase the number and level of commitment of the motivated people. A second positive feedback loop was found between the positive outcome of using active learning instruction and the strengthening of cultures/structures supportive of active learning.

Conclusions According to the model, there are two main take-away messages for those interested in promoting the use of active learning. The first is that all four components of the model are important. A weak or missing component may limit the desired outcome. The second is that desired outcomes are obtained and strengthened over time through two positive feedback loops. Thus, there is a temporal aspect to change. In all of the departments that were part of our study, the changes took at minimum several years to enact. While our model was developed using only high-use of active learning departments and future work is needed to develop the model into a full change theory, our results do suggest that change efforts may be made more effective by increasing the robustness of the four components and the connections between them.

Keywords Active learning, Departmental change, Instructional change, Undergraduate education, Grounded theory, Model development

*Correspondence:
Alexandra C. Lau
lau@aps.org
Full list of author information is available at the end of the article

Introduction

Research in STEM education has convincingly shown that use of active learning instructional strategies can increase learning, retention, and equity in undergraduate STEM courses (e.g., Freeman et al., 2014; Kober, 2015; NASEM, 2021; NRC, 2012). While progress is being made in terms of the use of these strategies in introductory STEM courses, they are still not the norm in most colleges and universities in the United States (Stains et al., 2018). In order to address the slow uptake of these strategies, research efforts have been focused on characterizing the drivers and levers that influence individual STEM instructors' decisions and ability to implement these strategies in their courses (e.g., Laursen et al., 2019). These research efforts have demonstrated that the challenges faced by instructors are multifaceted, with some factors related to the instructors themselves (e.g., lack of pedagogical training, belief systems about teaching rooted in teacher-centric learning experiences) and others related to the system instructors are working in (e.g., classroom infrastructures, institutional policies for promotion) (Henderson & Dancy, 2007; Lund & Stains, 2015; Shadle et al., 2017). However, even factors that might appear to be individual level are often related to the system. For example, a lack of knowledge about, or experience with, active learning as a student are both caused by the academic system that does not fully embrace active learning. Thus, while focusing change efforts on individual instructors is the most common approach taken by STEM change agents, it is also not the most effective (Henderson et al., 2011). The focus on individuals ignores the complex systems faculty operate in and makes the false assumption that evidence of effective teaching practice will directly translate into uptake of those practices (Henderson et al., 2010, 2011).

It is now becoming more common for change agents to treat academic departments as the most important unit within the academic system for instructional change (AAAS, 2011; AACU, 2014; Corbo et al., 2016; Fisher & Henderson, 2018; Knight & Trowler, 2000; Ngai et al., 2020; Quan et al., 2019; Reinholz et al., 2019; Wieman et al., 2010). It is the department that sets norms and policies around teaching and instructors often point to their departmental culture as a reason for not being able to implement active learning strategies (Sturtevant & Wheeler, 2019). Departments also have relatively uniform culture, as compared to the ways culture can vary across departments and institution-wide (Reinholz & Apkarian, 2018). Thus, sustainable department-level change requires changes in department-level structures and cultures (Eckel & Kezar, 2003; Henderson et al., 2011; Reinholz & Apkarian, 2018; Reinholz et al., 2019). Eckel and Kezar (2003) describe structures as visible aspects of an organization that shape how things are done. These include things such as policies, budgets, hierarchies, and decision-making structures. Cultures are the more informal factors that shape how things are done. These include the ways that people interact with one-another, the ways issues are framed, and the types of conversations that are seen as important (Eckel & Kezar, 2003). Many researchers argue that sustainable department-level change results from changing departmental structures and culture through ongoing conversations and relationship building (e.g., Huber & Hutchings, 2021; Reinholz et al., 2019). While we know about some of the barriers and levers for change (e.g., Austin, 2011; Henderson & Dancy, 2007; Laursen et al., 2019), we know much less about the specific aspects of structures and cultures that lead to sustainable change as well as how those structures and cultures can be put in place.

The Four Frames model is one change theory that has helped researchers to think about departmental structures and cultures in higher education, as well as the process by which change can occur. Reinholz and Apkarian (2018) adapted Bolman and Deal's Four Frames model (2008) from the organizational change literature to the context of STEM education reform at the department level. The Model defines culture as "a historical and evolving set of structures and symbols and the resulting power relationships between people." The four frames of culture are structures, symbols, power, and people. In order for a change effort to be successful, the theory states that all four frames of culture must be taken into account. The Four Frames model can be used by changes agents to understand the outcomes of an existing change effort, or to identify the levers and connections between them when planning a change effort.

Departmental action teams (DATs) are an example of a strategy to promote change at the department level by addressing its culture around teaching. DATs are a facilitated group of students, staff, and faculty that meet regularly over two to four semesters to implement a specific education and culture-related change in their department (Ngai et al., 2020; Quan et al., 2019). The DAT model offers a specific set of practices and principles that are likely to lead to department-level change.

While both the DAT model (as a particular change strategy) and the Four Frames model (as a change theory) are focused on departmental structures and cultures, neither provides much specific guidance about what sorts of structures and cultures are desirable. (Feola et al. (2023) identified a similar gap in the institutional change literature regarding the range and variability of change strategies and tactics used at that level.) For a change effort to be successful, it is often valuable to understand what the end state of reform could look like. A model of the

features of departments that have widespread adoption of instructional reforms can be used by departments and change agents to inform their specific change effort. The goal of the research presented in this paper is to work towards the development of such a model by exploring departments that have been successful at integrating active learning instructional strategies in their introductory courses.

Specifically, we leveraged survey data collected from 3769 instructors of introductory chemistry, mathematics, and physics courses (Apkarian et al., 2021; Vishnubhotla et al., 2022; Yik et al., 2022a, 2022b) in order to identify departments with high levels of implementation of active learning instructional strategies in these courses. These instructors represent 1,779 departments at 827 institutions. We sampled by department and institution, sending survey invitations to all faculty teaching introductory courses within each department. We aimed to get responses from multiple instructors in each department in order to understand individual, departmental, and institutional factors that are associated with the use of active learning instructional strategies. The survey data led us to focus on 16 departments that were in the top quartile of the departments represented in our study in terms of active learning instructional strategies used in introductory courses. The model of characteristics of departments with high use of active learning instruction in their introductory course that was developed from this grounded theory study is based on the analysis of interviews conducted with 27 instructors in these 16 departments.

Methods

Grounded theory

While, as discussed above, many researchers think of the department as the key unit of change and there has been some research on how to promote department-level change, we do not yet have a working model for instructional change at the departmental level that can be useful to guide or monitor change efforts. Thus, the goal of this research was to develop a better understanding of the features of high use of active learning (in introductory courses) departments and how these departments got that way. The goal of this study is to develop a model (i.e., a "theory") that describes the important characteristics and development of STEM departments with high use of active learning. Such a model will be useful in developing theories of change (Reinholz & Andrews, 2020) for STEM departments.

Because there has been little research conducted on what leads some departments to use high levels of active learning instruction, we draw on grounded theory, which is a research methodology characterized by openness to new ideas, a focus on explanatory power, and iterative data collection and analysis (Charmaz, 2006; Gibson & Hartman, 2013; Glaser & Strauss, 2017). Consistent with grounded theory, we prioritize our own empirical data in our initial theory-building.

Unlike many research traditions that begin with a theoretical framework, a grounded theory study typically begins with the data and the theory is then developed to fit the data (Charmaz, 2006). Prior literature is typically connected to study results at the end rather than the beginning of the analysis (Charmaz, 2006). Thus, we discuss relevant literature along with the results rather than in a more traditional literature review. Of course, all of the members of the research team are familiar with some of the literature related to academic departments and to high-quality teaching, and we also all have our own ideas and experiences about academic departments. The two core ideas mentioned earlier (departments are a key unit of change, and sustainable change requires changes in structures and cultures) are core knowledge commitments that did shape our study design. For example, we chose to focus the study on the department level. This was due to the results of the survey portion of our study (Apkarian et al., 2021; Vishnubhotla et al., 2022; Yik et al., 2022a, 2022b) as well as our awareness that others think of departments as a key unit of change (e.g., Corbo et al., 2016; Fisher & Henderson, 2018; Knight & Trowler, 2000; Ngai et al., 2020; Quan et al., 2019; Reinholz et al., 2019; Wieman et al., 2010). Similarly, the types of questions we asked during interviews were designed to get at both structural and cultural components.

Data sources

The data for this study are interviews with instructors who work in departments where there is high use of active learning in their introductory courses. We identified these high active learning use departments based on survey data we collected in spring of 2019. We conducted a nationwide survey of 3769 postsecondary chemistry, math, and physics instructors who had taught their discipline's introductory course within the past two years. For this survey, we used stratified random sampling by institution type to ensure representative samples from different institution types in the United States (two-year colleges, four-year colleges, and universities). At each institution selected, we identified instructors who had taught one of the target introductory courses in chemistry, mathematics, or physics. One of the items on the survey asked participants to report the percent of class time their students spend listening to the instructor lecture or solve problems; we used this item as a proxy for active learning.

That is, we assumed that a low percent time in lecture corresponded to a high percent time students are engaged in active learning.

We identified high active learning use departments by looking for departments in our survey data set that had multiple instructors (3+) in the top quartile of their discipline and institution type in terms of self-reported percent class time their students spend in *non-lecture* activities. Equivalently, these were the departments that had multiple instructors in the first quartile of their discipline and institution type in terms of self-reported percent class time their students spend listening to the instructor lecture. These quartile scores, derived from the survey data, are shown in Table 1. Instructors needed to lecture ≤ 30–50% of class time (depending on discipline and institutional context) to be in the top quartile of active learning users. For example, when identifying physics departments at graduate degree-granting institutions to interview, we were looking for departments in our survey data set that had multiple instructors reporting lecturing 30% of class time or less. In addition, we aimed for variation in institution size, selectivity, geographic location, etc., when choosing departments to interview.

Table 1 First quartile scores of percent time lecturing for each discipline and institution type combination

Discipline	Institution type		
	2-year college	Undergraduate degree-granting (%)	Graduate degree-granting (%)
Chemistry	Less than 40% of class time in lecture	40	50
Math	35%	40	40
Physics	30%	35	30

Data are from the departments in the survey study. Instructors in the first quartile of percent time lecture are in the top quartile of percent time in active learning

From each identified department we invited two instructors who had completed the survey to participate in an interview. If one declined, then we invited additional interviewees until we had two interviewees or exhausted the list of survey respondents (there was a minimum of three) from the department. We collected 29 interviews with instructors from 18 departments, spanning math, chemistry, and physics, as well as different institution types. Two departments were removed from analysis because of the peripheral status of the solo interviewees, evidenced in the interview by their limited view of their department's culture, history, and practices. The interviews removed were from (1) a graduate student instructor at a university mathematics department; and (2) an adjunct faculty member at a two-year college chemistry department. Table 2 reports the disciplinary and institution type range of our interviews. The goal was to sample two departments in each category, and two instructors from each department, but this was not always possible. It was especially challenging to reach the instructors at the two-year colleges; we often received no response to our inquiries, or the instructors lacked the time to participate in an interview. The underrepresentation of the two-year college departments in our interview sample is a limitation of our study.

The interview protocol (see Additional files 1) had two major sections: (1) individual teaching practice (focused on introductory courses) and (2) organizational and departmental context and culture. Note, the interview questions about individual teaching practice allowed us to corroborate participants' survey responses regarding their use of active learning. Interviews were collected between Spring 2020 and Fall 2020. A few interviews were completed before the COVID-19 pandemic caused the shutdown of most in-person classes in Spring 2020, but most interviews were completed during the shutdown. We asked participants to respond to interview questions based on their

Table 2 Interviewed individuals (from N departments)

Discipline	Institution type			Total
	2-year college	Undergraduate degree-granting	Graduate degree-granting	
Mathematics	1 interview (representing 1 department)	5 (3 departments)	3 (2 departments)*	9 (6 departments)
Chemistry	0 (0 department)**	3 (2 departments)	4 (2 departments)	7 (4 departments)
Physics	4 (2 departments)	3 (2 departments)	4 (2 departments)	11 (6 departments)
Total	5 (3 departments)	11 (7 departments)	11 (6 departments)	27 interviews (16 departments)

Number of individuals and departments from each discipline and institution type used in this study. (Prior to dropping two interviews, *4 interviews (3 departments); **1 interview (1 department).)

pre-COVID-19 teaching, but we did also briefly discuss their pandemic teaching experience.

Model development

Consistent with grounded theory (Glaser & Strauss, 2017), the goal of the analysis was to develop a theory or model that describes the characteristics of these departments relevant to their high use of active learning instructional strategies. Data analysis was an emergent and collaborative process involving authors ACL, CH, CM, MS, and MD, all with a variety of backgrounds and experiences as educators, change agents, and educational researchers. The analysis process was focused on departments and, keeping with the grounded theory approach, involved constant comparative techniques (Creswell and Poth 2016). It also involved more than one team member independently analyzing each interview as well as regular team discussions to reach consensus about knowledge claims that could be made.

We initially examined one department at a time, taking evidence from both of the interviews of instructors in that department. Each member of the data analysis team would independently analyze the department and write a short paragraph explaining the important factors that led to this department being in the top quartile of active learning users. Given the focus of our study on individual, departmental, and institutional factors that may effect the teaching practice of a department, we were attuned to these multiple levels when reviewing interviews. For each interview, we noted individuals who influenced teaching practice (those "motivated" to use active learning), as well as examples of culture factors (at the department or institution level) that influenced active learning use. The specific factors (codes) emerged from these excerpts. For example, if the interviewee talked about how their department chair encouraged people to use active learning, that would be coded as "Motivated Person: Department Chair". If the interviewee described teaching evaluation policies that rewarded active learning use, that would be coded as a cultural factor, "Evaluation of teaching practices". After individually analyzing the transcripts, we would then come together to discuss our interpretations. When disagreements in interpretations arose, we would discuss those until we reached a consensus about what claims we could make based on the data. After doing this for five departments, we stepped back and reviewed the factors that had emerged from the data. We recognized various types of individuals who influenced teaching practice (e.g., education researchers, institutional leaders), a range of cultures or structures that supported active learning use (e.g., funding for teaching reforms, hiring for commitment to teaching), and a pattern of connection between the codes. This led us to develop an initial model of characteristics of departments with high use of active learning. This preliminary model stated that motivated people helped develop cultures and structures supportive of active learning, and these cultures and structures helped increase the number of motivated people. Connected to these two high-level factors were examples of the codes, and additional connections such as motivated people leveraging funding opportunities for teaching reform.

We then tested the model by analyzing four additional departments in our data set. After identifying the important factors for a department, we would compare those items to the factors and connections in our working model. We refined the model, adding factors or drawing new connections between them, when the current version of the model was no longer descriptive of the departments in our data set. This would happen, for example, when an interviewee would describe a factor important for their department's active learning use that we had not noted in the previous interviews we had analyzed. In this case, the code would be added to the model, often as a new example within a category of codes (e.g., another type of motivated person). Occasionally, the new code would cause us to re-examine the connections between codes. For example, we identified a number of individual codes that all represented examples of opportunities people had leveraged to increase active learning use and so we created a code category called "Opportunities" which was connected to the motivated people category of codes. After any refinement to the model, we then returned to the previous interviews we had analyzed to check if the new code or connection was present or was instead unique to the interview at hand. After collectively analyzing nine of the departments, we then separated into two groups, with each group focusing on one additional department at a time. The group members (2 or 3 people) would each independently analyze the interviews for that department and then meet to come to agreement. After each cycle (usually two departments analyzed by two different sub-groups), all team members would come together to discuss their analyses and revise or refine the model based on the newly analyzed departments. The refined model was also checked to ensure that it still accurately described the previously analyzed departments. Before analyzing the next two departments, we would mix-up the members of the analysis sub-groups to promote heterogeneity of ideas and the prevention of bias. This process continued until all departments had been analyzed. The final model is presented in the Results section of this paper.

Periodically throughout the analysis process, we would present our findings and working model to all members of the larger project team who were not involved in

the analysis, as well as to external groups. The feedback from these presentations was a crucial part of the iterative model development process as it helped the analysis team identify components of the model that needed clarification and connections that needed to be confirmed by a closer look at the data.

Author positionality and trustworthiness

One of the strengths of this project is the diversity of identities and experiences that each of the eight members of the research team brought to the project. Team members represent different institutional types, different racial and ethnic backgrounds, different genders, different job responsibilities at their institutions, different career stages, and different levels of experience in conducting research on departmental change.

In addition to having a diverse research team, we also designed our study to address Lincoln and Guba's (1985) four components of trustworthiness for a qualitative research study: credibility, transferability, dependability, and confirmability. Credibility refers to the extent to which the findings accurately represent the experiences of the participants. The use of multiple data sources was an important contributor to the credibility of this study. We sought to interview two people from each department and the final model was built using data from all of the departments. Transferability refers to the extent to which the findings can be transferred to other contexts or groups. In this study, we provide rich descriptions of each of the model components as well as two extended examples to help readers understand how the findings might apply in other contexts. We also discuss Chasteen's (2021) successful application of our model in a related context. Dependability refers to the extent that research findings are repeatable. As described in the Model development section, the project unfolded in several distinct phases and key decision points are articulated. Confirmability refers to the degree to which the results are not influenced by the researcher positionalities. As discussed above, the project team was diverse. In analyzing the interviews and developing the model, multiple researchers were involved in each step, and there was much discussion and revision. For example, each interview was initially analyzed by more than one researcher. These researchers would then meet with one-another to discuss and, once agreed on, bring their analysis to the entire research team where anyone could raise additional questions.

Results

The Model of the characteristics of departments that are high users of active learning (hereafter referred to simply as "the model") is displayed in Fig. 1. The model has four components, one outcome, and two feedback loops. We will first present a general overview of the model, and then give detailed definitions and examples of each element in turn. We will follow this with examples from two departments to show how the model captures the high use of active learning in the introductory courses in those two departments.

The four components in the model include: Motivated People, Knowledge about active learning, Opportunities, and Cultures and Structures that support active learning. The outcome in the model is High Use of Active Learning in Introductory Courses. There is an iterative and positively reinforcing cycle between **people motivated** to increase active learning use in their STEM department's introductory courses and departmental and institutional **cultures and structures** that promote active learning use. The motivated people help to develop and enhance a culture and structures supportive of active learning, and in turn the culture and structures help to grow the number of people motivated to reform the teaching of introductory courses in the department. The motivated people have **knowledge** of research-based instructional strategies and the results from discipline-based education research. They leverage **opportunities**, both internal and external to their department and institution, to increase the active learning used in introductory courses in their department. The positively reinforcing cycle between people and culture leads to **high use of active learning** in introductory courses in the STEM department, and this becomes established as part of the department's culture, thus feeding back into the cycle that promotes active learning use.

Model elements

We now define each element of the model. Examples of the four components are included in Table 3; the full codebook is included with the Supplementary Materials (See Additional File 2).

Motivated people

In the model, Motivated People are defined as members of the academic institution who are driven to increase the use of active learning in introductory STEM courses. They may be leaders of pedagogical change efforts, or those who have bought into such change and are currently perpetuating and supporting the change. We identified four main types of motivated people: education researchers located in a STEM department, STEM faculty (who are not education researchers), department chairs, and institutional leaders. Education researchers located within a STEM department are those who have expert-level knowledge of education research, either because they were trained in discipline-based education

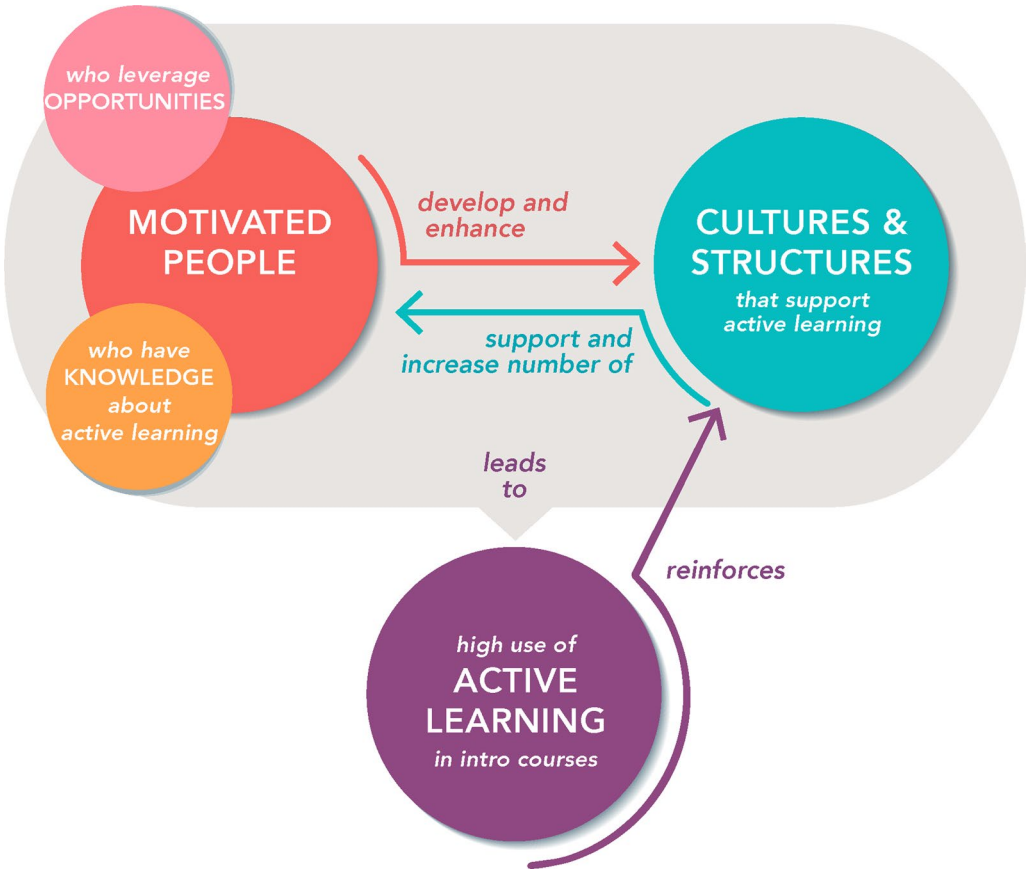

Fig. 1 Model of the characteristics of departments that are high users of active learning. These STEM departments have motivated people who leverage opportunities to incorporate and sustain active learning in the introductory courses, and are knowledgeable about active learning. The departments also have cultures and structures (at the institution and department level) that support active learning use. These two elements, motivated people and cultures and structures, mutually reinforce each other and lead to high use of active learning in the introductory courses in the department. This high use then reinforces the existing cultures and structures and a positive feedback loop continues

research and/or they are currently conducting education research. STEM faculty who are not department chairs and not involved in education research may also be motivated to lead and/or contribute to the adoption of research-based instructional techniques in introductory courses. In every department studied, there was a least one motivated person who fell in this category. Department chairs who support teaching reform in concrete ways also fit the definition of motivated people. In most departments studied (14/16), one of the motivated people was a department chair. Lastly, motivated people can include institutional leaders, such as deans or other administrators, who tangibly and explicitly push for the adoption of active learning in introductory STEM courses. In all but one of the departments studied there was more than one type of motivated person. The frequency of the specific examples of motivated people may indicate that certain types of motivated people (i.e., STEM faculty and department chairs) are particularly influential. This is perhaps unsurprising as chairs often control department resources, and the majority of faculty in STEM departments are STEM faculty who are not education researchers.

Knowledge about active learning

In our interview sample, all of the motivated people had knowledge, or at least awareness, of active learning, research-based instructional strategies (RBISs), and/or results from education research. This knowledge was often gained through a mix of local and national resources. National resources include traditional dissemination platforms like research journals, books, published curricular materials, conference presentations, and workshops run by professional societies. Knowledge was also gained from local resources such as an expert in an RBIS who was located at one's institution or in the geographic region, or training from

Table 3 Model components and examples

Component	Examples	Number of departments with component
Motivated people		16 overall
	Examples	
	STEM Faculty (who are not education researchers)	16
	Department Chairs	14
	Education Researchers	9
	Institutional Leaders (e.g., Deans)	7
Knowledge about active learning		16 overall
	Gained from:	
	Local education researchers or Teaching and Learning Ctr	11
	Published research and curricula materials	9
	Conferences/workshops run by Professional Societies	8
	Graduate School	4
Opportunities		16 overall
	Examples	
	Funding opportunities, internal to institution	9
	Institutional Pressures (e.g., graduation rates/DFW)	9
	Hiring opportunities for active learning use	8
	Funding opportunities, external to institution	4
Cultures and Structures that support active learning		16 overall
	Institution-level	
	DBER presence on campus	12
	Evaluation of teaching practices	9
	Teaching & Learning Center	7
	Type of students need/benefit from active learning	5
	Department-level	
	Collaborative culture around teaching in department	16
	Culture of continual innovation and exploration (often supported by new faculty)	14
	Class layout and/or size conducive to active learning	13
	Send people to external professional development	8
	Hiring for commitment to teaching	7
	All faculty teach intro courses	5
	Common curriculum	5
	Class scheduling–large block of time	5
	Support for faculty autonomy	3
	Multi-level (arising from department and/or institution)	
	Value undergraduate teaching	9

Examples of the four components in the model and the number of departments the example was present in. We include examples that were present in 3 or more departments. Total number of departments in our analysis set is 16

the institution's teaching and learning center. Some instructors were exposed to active learning during their graduate careers because their graduate department had faculty engaged in discipline-based education research, made use of RBISs in their courses, and/or had a learning assistant program (Otero et al., 2010).

Opportunities

The motivated people in departments with high use of active learning in their introductory courses leveraged opportunities to create and sustain the culture of active learning use. These opportunities came in two types: (1) opportunities specifically designed to support active learning (e.g., grants designed to transform

courses) and (2) opportunities that are not necessarily designed to support active learning, but can be directed to advance active learning (e.g., hiring). In the former category, interviewees described funding opportunities (both internal and external to their institution) designed to support teaching reform. These funds were used for, e.g., building active learning classrooms and developing curricular materials to implement in those environments. In the latter category, participants described hiring intentionally for instructors who use active learning, regardless of the intended teaching and research responsibilities of the open job position. It should be noted that direct opportunities to hire someone to lead pedagogical transformation existed as well. Institutional pressures also served as opportunities that could be leveraged to implement active learning in introductory courses. Sometimes this pressure was a university initiative directly promoting active learning uptake, and other times these were calls to improve graduation rates, which led departments to reassess their undergraduate program and implement active learning in the introductory courses to increase retention.

Cultures and structures that support active learning

Cultures and structures that support active learning exist at both the institution-level and department-level, and they arise in a number of forms. For a full list of examples, see Table 3; here we will highlight some of the most common cultures and structures discussed by our interviewees as supportive of active learning use. In the Supplementary Material, we provide a full set of definitions for all culture and structure examples. Note, the mere presence of one of these cultures or structures does not automatically imply support for active learning; the departments in our data set were only coded for the culture or structure example if it was directly connected by the interviewee to active learning use in their department.

The most common cultures and structures (mentioned in interviews from 10 + departments) include: collaborative culture around teaching in department; culture of continual innovation; DBER presence on campus; and class layout and/or size. Collaborative culture around teaching in the department is defined as frequent teaching collaboration among at least some of the faculty in the department that facilitates active learning adoption. This collaborative culture can be enacted in multiple ways: e.g., instructors frequently talking to colleagues about teaching and what is going on in their classroom; sharing innovative curricular materials; coordination between course sections (provided the coordination is described as an affordance for active learning use); observing colleagues' classes and providing feedback; a norm of troubleshooting classroom challenges with colleagues; instructors sharing notes about what they learned at teaching professional development; and/or reforming a course in conjunction with another instructor. All of these conversations and idea sharing are directed towards the uptake of active learning. An important characteristic of this collaboration is that it is routine, happening regularly rather than as a one-time occurrence.

A culture of continual innovation and experimentation describes an orientation among at least some faculty in the department to constantly improving one's teaching. These instructors are continually seeking to improve through implementing and experimenting with new research-based teaching techniques in order to best serve their students. This continual innovation was often described by interviewees as being driven by new faculty who brought knowledge of teaching innovations and an openness to using active learning.

We define a discipline-based education research (DBER) presence on campus rather broadly, requiring that there are multiple people on campus who are involved in the DBER community, but not necessarily publishing their own DBER research. This involvement in the DBER community means that a number of STEM instructors on campus are knowledgeable of the products of DBER or have even created some of those products (even if they themselves did not conduct extensive research on the products). Importantly, this DBER presence has to extend beyond a single department in order for it to count as a campus-wide presence. Examples of this DBER presence include having instructors in multiple STEM departments who attend DBER conferences, or having a learning assistant program that is active in multiple STEM departments.

Class layout and/or class size captures if the introductory courses in the department are held in a classroom conducive to active learning use, and/or the courses are capped at a small size and this is cited as affordance for active learning use. In terms of classroom layout, examples include studio-style classrooms (e.g., Knaub et al., 2016), and lab spaces that are used for the "lecture" portion of class to facilitate group work. Regardless of the exact setup, the space is described as an important part of the local environment that supports the use of active learning. The classroom space could be the result of a particular institutional initiative or funding opportunity, but this was not frequent in our sample.

Outcome: high use of active learning in introductory courses in the department

The outcome in the model, high use of active learning in the introductory courses of a department, is defined as described in the Methods section: three or more

introductory course instructors in the department are in the top quartile of active learning users for their discipline (chemistry/math/physics) and institution-type (2-year college, undergraduate degree-granting, or graduate degree-granting), based on our survey results. Importantly we found that in the departments we studied, once active learning was implemented in the introductory courses, it started to become part of the departmental culture for these courses. As more instructors adopted active learning when teaching the introductory courses, and the longer active learning had been in place in those courses, the more the use of active learning became routine and often even expected for the introductory courses in the department. Thus, once high use of active learning in introductory courses is established, it becomes not only an outcome of our model, but also a reinforcing cultural factor.

Examples of the model

We now present examples from two different departments of how the model helps explain the high use of active learning in the departments' introductory courses.

Example one

Our first example comes from the physics program at "Pine Community College" (a pseudonym). Figure 2 displays the ways each model component was present in the Pine physics program. The physics program is housed in the physical science division of the college. The physics portion of the division has three full-time faculty, as well as adjuncts. We interviewed two of the full-time physics faculty: Paul and Patricia (also pseudonyms). As Paul states, "I was hired at the college as the first physics faculty ever, so there was no physics program prior to me coming in." He has been part of the division for over 20 years. Patricia, the second permanent physics faculty to be hired, has been in the division for 10 years.

Patricia describes that the pedagogy used across the physical science division is pretty similar. As she

Fig. 2 Model applied to Pine Community College physics program. Within each model component circle, the bullet points list the examples that were present in the department. In the text, the narrative is constructed to tell the essence of the department's story as concisely as possible, so not all examples of each model component are discussed. The asterisk (*) indicates the examples that are not included in the narrative text

states, they all use a pedagogy that is based on a specific research-based instructional strategy. Paul illustrates a typical day in his introductory physics course: "I'm not going to be lecturing. Even though there's a lecture period it's going to be activities, it's going to be scaffolding, it's going to be building, it's going to be labs to reinforce or to bring out misconceptions and ideas. It's going to be using TIPERS, tasks inspired by physics education research, to either reinforce or bring out ideas." The other physics instructors similarly use a large amount of active learning when they teach the introductory courses, and they all use a workbook Paul created as their guide. However, Paul explains, "How we approach them [the techniques], the order we do them is very different. How we utilize non-traditional classroom management is considerably different between the three of us. And then sometimes the content is radically different. In terms of what we emphasize and what we don't emphasize." Indeed, Patricia explains that she has, "added lots of different things [to Paul's workbook] that weren't there before. Some things that I felt like needed a little more scaffolding. … I might do a different set of TIPERS in that class… so him and I have slightly different twists on the class." Instructors have flexibility to customize their offering of the introductory physics course, but they all are using techniques based in physics education research.

Our model helps explain how the high use of active learning in the introductory physics courses came to be at Pine Community College. Paul completed his **PhD in physics education research** and was very **motivated** to implement active learning. Coming out of graduate school Paul had two job offers, "one where I was going to be a fourth faculty member or at [Pine] where I was going to be starting the program from scratch. That's the reason I chose it [Pine]….it was primarily that ability to build it and mold it as I wanted from the start." Paul brought his **knowledge and training in research-based instructional strategies** to his teaching at Pine. Early on, Paul became **chair** of the physical science division and in that role he **leveraged the opportunity to hire** new faculty. As he recalls, "I had a stint as eight years as the chair of science and math and during that time I took a lot of, excuse me, six years [as chair], Um early on and hired probably in the physical sciences anyway, two-thirds of the faculty during, that are still here, during that time period with the bent of making a division, an area that is about embracing, reforming, embracing new ideas, embracing change." With this strategic hiring, he **increased the number of people** in the division who are **motivated** to use active learning, and he **developed a culture** that expected instructors to be **continually innovating** in their courses.

The chairs who have followed Paul have maintained this emphasis on active learning in the division. As Paul shares, "The next two chairs that followed me… all have really continued that trend… [one of them] was actually hired a year after me, but she became influenced by having conversations with folks and became a much more non-traditional instructor. [The other] was, I will admit, one of my hires as a young, recent PhD grad who I saw as somebody that was willing to embrace and engage and so he was kind of a protégé of mine. He has just continued that… those…continued to build what I started." Paul helped establish the **culture** in the division to **hire for people committed to teaching** using active learning, and this has **increased** the **motivated people** in the division, **some of whom later lead the division and continue to develop this supportive culture**.

Patricia corroborates this in her interview, explaining, "I think when I came in, it was just [Paul] teaching classes. And so when I came in we got together as a team and you know, it's his vision, but it's now our vision for this division. And so we really try to hire people who fit that criteria…our chemistry division, they push their instructors to go take the [specific RBIS] courses and be educated in, in this method…we hire the right people. Right, we will not push classes to go if we don't feel like it's going to be done well, you know, so we want to make sure that we have, like our adjuncts are, majority of them teach the same way we do." The **hiring culture** is robust, extending past full-time faculty to adjuncts as well. Through hiring and increasing active learning users, they have established a division **cultural** expectation that instructors use **innovative** techniques in their **teaching**.

The **motivated people** hired to join the department are **knowledgeable** of active learning. Most of the division, including Paul, Patricia, and the current division chair, have **taken courses** on the use of a specific RBIS. Patricia says that this common training means that, "Everybody in our division is pretty much approaching their content from a student learning point of view and innovating in the areas of educational research and stuff like that… we are all coming from a point of view that is very supportive of, of changing and innovating within our classrooms." These **motivated and knowledgeable people** have contributed to a department **culture that values undergraduate teaching**, prioritizing student learning by implementing innovative teaching techniques.

The **motivated people** have additionally built a **collaborative culture** around teaching that supports **continual innovation** in the classroom. When Patricia joined the division as a physics instructor, "it was just [Paul] himself and I was very open to learning as much as I could learn. And then I had my own ideas of how I wanted to do things, but I was noticing that his FCI

[Force Concept Inventory] scores and things like that were, significantly higher. And I was just always picking his brain and asking him questions like how did he do that? And then once I saw what he did, then I changed, okay, now what can I do to improve on this and take it one step further. And so I worked very closely with him for a long time on some of this and I still do." Patricia had graduate-level training in science education and the specified RBIS upon joining the division, but she was still motivated to learn more by working with Paul. Once she understood Paul's pedagogical approach, she was able to further improve her teaching practice by building on Paul's techniques.

This **collaborative culture** extends beyond Paul and Patricia. Paul says that the three full-time physics faculty meet weekly to "discuss failures. Success". The full-time faculty "gladly help our adjuncts. We help each other. We have conversations about what worked, what didn't, you got any suggestions for this?". This **collaboration** helps with active learning implementation and **keeps instructors motivated.** Patricia says, "I love the collaboration. I think that's really the key is that we are really open. I learn a lot from our… from everybody in on our campus, but more importantly from our division…And I think that having other instructors that come from that same point of view is just crucial because that's what gets you up in the middle of, you know, every day take, go back to work. Cause you're working with people who are like minded. And I think that's, that's really important." From this excerpt, we see how a **culture of collaboration and shared commitment to innovation in undergraduate education** helps **support** the instructors who are **motivated** to use active learning.

When describing the history of teaching in the division, Paul talked about how he was supported in promoting active learning by a **motivated person in the administration**: "And so it was a very cognizant decision by both myself and actually at the time the VP of… academic affairs with the college, to build this kind of area to try to help you know, improve success rates and things in these areas." The Vice Provost (VP) supported **motivated faculty** in **leveraging grant opportunities (funding)** and the opportunity to build new **classroom space**. Paul explains, "when we redesigned all our science rooms… [the VP went] to the architect and saying, you need to meet with the faculty individually to design, design their rooms to meet their needs, not having conversations with the administration and [the VP] really force[d] that from that kind of support downward, it really was an institutional decision. And it, that was the culture of the college and that's one of the reasons I'm still there." In this excerpt, Paul explicitly **links motivated people to opportunities** to increase active learning and shows how the **motivated vice provost helped establish** an *institutional* **culture supportive of active learning**.

One of the **structures** the institution provides to **support active learning use** is funding to **send faculty to external professional development**. Paul describes, "the college…has always had a robust ability for people to do professional development. Whether that's attend meetings, whether that's going in your area or outside your area. I get [nearly $4,000] a year in professional development money for travel." This tangible **support for teaching professional development demonstrates** the institutional **culture supporting active learning**, and how that **culture can help support and increase the number of motivated people** at Pine with strong **knowledge of active learning**.

Through a positively reinforcing cycle between motivated people and a culture supportive of active learning use, the physics instructors at Pine Community College were able to establish a high level of use of active learning in their introductory physics courses. Paul, supported by the VP of academic affairs, was able to hire instructors who were all motivated to use active learning. This developed a culture in the division of continual innovation in the classroom which was further supported by the institution-level culture of valuing undergraduate teaching. The instructors in the division are open to collaboration and they provide pedagogical support to each other. Through Paul's work and his hires, they developed an expectation of using active learning in the physical science division. The chairs who followed Paul continued to enhance the teaching culture and increased the number of instructors motivated to use active learning with the hires that they made. All of the hires were knowledgeable of active learning, and many were or have since been trained in the use of a specific RBIS. Instructors in the department have additionally been able to leverage funding opportunities and new classroom buildings to support their active learning use.

Example two

Our second example (see Fig. 3) comes from the chemistry program at "Cedar University" (a pseudonym). Cedar University is a large state school, with a focus on both teaching and research. We interviewed two members of the chemistry department: Christine and Christopher. Christine is an associate professor as well as vice chair and undergraduate advisor in the department. In describing Cedar University, Christine shared that, "Teaching is one of our key tenets. So teaching and research are both, I would say, equally valued." Christopher is a pre-tenure assistant professor in the department. The introductory sequence offered in the department includes introduction to general chemistry ("intro to gen chem"), general

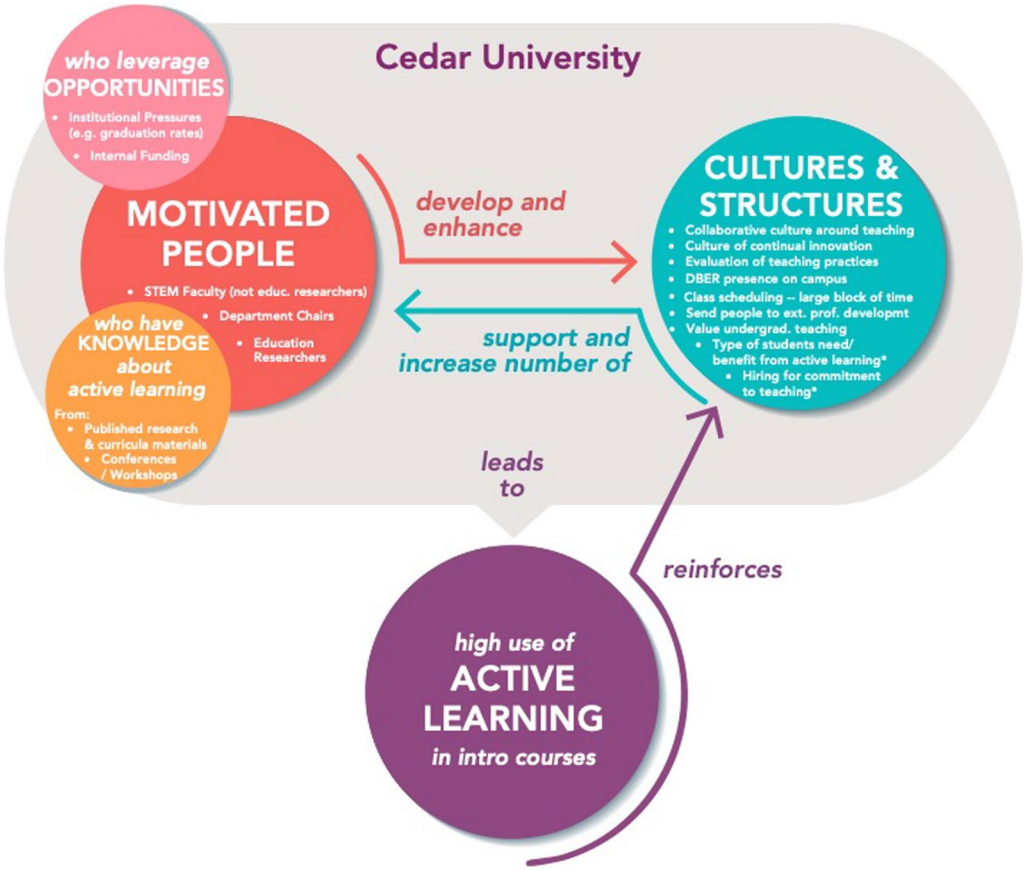

Fig. 3 Model applied to Cedar University chemistry department. Within each model component circle, the bullet points list the examples that were present in the department. In the text, the narrative is constructed to tell the essence of the department's story as concisely as possible, so not all examples of each model component are discussed. The asterisk (*) indicates the examples that are not included in the narrative text

chemistry one ("gen chem 1"), and general chemistry two ("gen chem 2"). Christine has taught the intro to gen chem course for a number of years, and Christopher regularly teaches gen chem 2.

The intro to gen chem course is a remedial class for students who need additional preparation before advancing to gen chem one. The course is scheduled so that the lecture period and activity section are back-to-back. Christine describes that she, "alternate[s] between lecture and problem solving throughout the time period…I always have them turn so that they're in groups of four…and we also have like two foot by three foot dry erase boards that each group has. And so even during the lecture we do group problem solving." Christine integrates the lecture and activities throughout the class period, and even during her lecture portions she engages her students by asking, "'what do we think, how do we feel about this concept?' Sort of like thumbs up, thumbs down, kind of responses." There are a number of instructors who teach the intro to gen chem course, and Christine has observed many of them teach as she has served as the course coordinator. There is a range of teaching styles among these instructors. Christine relayed, "I would say like…80% of our faculty interject questions throughout their lecture, whether it's just like a pop-up multiple-choice kind of thing, um, a lot of people use fake clickers. So they have like the paper in the four spots." All of the instructors make their lectures interactive, but some instructors intersperse group work between lecture bursts while other instructors reserve more active engagement for a separate part of the class period.

Similarly, there is a range in the pedagogy used in the gen chem two course. Christopher summarized, "There's a relatively broad spectrum. So there are definitely some older faculty who, really just like, just lecture…Like, 'we're going to give you information. You need to tell it back to us come exam.' Right. Um, I guess I would see myself in the people who, and there are other faculty who do similar things to me, I think who, you know, I, I have not fully gone to a flipped class by any means. Right. I've only done, implemented sort of relatively modest group work components to the course, but I have attempted to make

it more engaging and attempted to focus on problem solving and critical thinking and conceptual understanding. Um, and then I have another colleague who has fully flipped the class, um, to, you know, to the point that there are no, no lectures at all right. Just group-based problem solving with him around to like help the students progress through." While there are a few instructors who have not incorporated any active learning into their gen chem two course, the majority of instructors use at least some techniques. Among the range in pedagogy used in the gen chem two course, Christopher places himself in the middle. As he describes, "when I am lecturing content, like, like I'm going through concepts, I have incorporated clicker questions into the, into the PowerPoint to try and get students to be engaged. But I would say most of the class time is spent working problems…I am working the problem on the board, but as I'm working through the problem, I'm constantly soliciting input from the students as far as what the next step is…I attempt to solicit input and engagement from the students throughout while we're working through those example problems." Christopher lectures during his class period, but he has implemented techniques to make those lectures interactive.

The chemistry department at Cedar University provides an example of a number of motivated people, sometimes independently and sometimes collectively, making changes to their teaching and developing a culture that together leads to an overall high level of active learning use in the intro courses in the department. The evolution of teaching in the intro courses in this department is not quite as straightforward as at Pine Community College, but our model elucidates the factors contributing to the current pedagogical state.

There are **a variety of instructors** in the introductory courses, including and extending beyond Christine and Christopher, who are **motivated** to use active learning. For example, Christopher told us about another gen chem 2 instructor, Carl, who has flipped his section of the class (and also uses that technique in the upper-level courses he teaches). Cedar University has an initiative to improve its student graduation rates and Carl was able to **leverage** the funding **opportunities created by this institutional pressure** to transform his gen chem course. Carl "received an internal grant to do that [flip gen chem] through this [graduation] initiative." The use of a flipped classroom now extends beyond Carl, as well. As Christopher relayed, Carl "flipped analytical chemistry first…he was the first person in the department to, to make that radical of a change in his teaching style. [Another colleague] was unhappy with how inorganic was going. So … she got his materials, talked with him, got guidance from him, but then developed her own spin on that. Another physical chemistry colleague has also worked with, with [Carl] to develop a flipped version of that class." Carl is a **motivated faculty** member who has helped **develop a collaborative culture** around teaching by aiding colleagues in implementing their own flipped classrooms, thus **supporting fellow motivated faculty** in using active learning.

Christopher himself has helped **develop a collaborative culture** around teaching in the department. He shared, "myself and another colleague took the initiative to develop standardized learning objectives for the [gen chem 2] course, and also to develop a set of materials that are shared. So like my lecture notes are shared with all of the new instructors, but it doesn't mean they have to use them. Right. But they are provided a set of working lecture notes, they are provided a common final that was decided by four of us faculty who teach the course." Previous to Christopher and his colleague's efforts, there was not a common set of learning objectives across the different sections of the gen chem 2 course. By collaborating with colleagues to develop these learning objectives, as well as a common final, Christopher helped develop a more collaborative culture around teaching in the department. In terms of sharing materials with colleagues, Christine reported a very similar situation for the intro to gen chem course: "When I was coordinator, what I would do is, you know, send everyone my complete packet of materials. And so I had problem sets, which then morphed into activities, right?… I provide them with as much information as they want." Collaboration can be enacted in many ways, from sharing course materials, to collectively determining the objectives for a course, to working together to implement a new teaching technique.

The **motivated people** in the department also include **chemistry education researchers** (CER). These faculty regularly teach courses in the introductory sequence. Christine explained the impact of the CER faculty on the intro to gen chem course, sharing, "Two of our three chemical education researchers are actually teaching our introductory course right now. And, and then our full-time lecturer is actually a chemical education/physics education researcher. We have a very strong influence. And so I would say that weirdly, that course [the intro to gen chem course] more so than any other course, has, is constantly evaluating the value in what we're covering…they also have, you know, this chemistry placement exam…And we have also started implementing that as part of our final exam in the introductory chemistry class…So we've been doing some evaluations based on those results as well." The **CER faculty** are contributing to a **culture of continual innovation** in the classroom by continually assessing the outcomes in the intro to gen chem course and reflecting on the goals of that course.

They also bring **knowledge** of active learning to the department.

One of the senior CER faculty helped drive change in the **class scheduling** so that it was more conducive to active learning. As Christine shared, led by this CER faculty member, "we kind of made a push in our department, to our department chair, to change all of our scheduling, so that the lecture and the activities for both intro to gen chem and gen chem one, were back-to-back so that you had your instructor the entire time, for both parts." This schedule change led to greater continuity between the different parts of the course and allowed for easier integration of activity into the "lecture" portion of class. Christopher explained, "first semester general chemistry has an activity component to it. So it's sort of like a built-in recitation. So, it can either be like a separate thing where you have like, here's the hour and 15 min long lecture, break, recitation, or it can be all interwoven into one thing. And I think [the CER people] sort of integrate the recitation…I think they do do group-like things and part of that's facilitated by having this extra activity time that's built in, or they have some malleability in scheduling because of that." **Motivated faculty** members helped **develop a culture and structure supportive of active learning by transforming** the way some of the introductory **courses** in the department are **scheduled**.

The influence of STEM education research spans beyond the CER faculty. Christopher reported, "Well, I think many of us know, right. That from, from the large amount of chemical, chemistry education research, right. That, you know, just straight lecturing without any attempts to engage students is not effective. And so, you know, I think those of us in the department who care about being effective educators are thinking about ways of better engaging the students." He states that many of the faculty have **knowledge of the results from chemistry education research** and the **faculty** who are **motivated** to teach better are trying to enact that knowledge in their classrooms. Christopher also stated that the university has, "a center for STEM science education. So there are members of biology, physics, and chemistry, maybe geology is, there must be math people too. So there are other STEM education researchers in the college, which I also think probably helps to foster that side of things [hiring CER people]." There is a **culture of DBER on campus** which supports the CER presence in the chemistry department.

The **motivated people** currently extend to the **department leadership** as well. The chair of the department uses many active learning techniques in his classroom. Christine relayed, "[the chair] is really into creating active learning classrooms. So he actually got a grant to create an organic chemistry, active learning classroom where the tables do pivot easily and that kind of thing, and dry erase boards everywhere and monitors everywhere." Not only is the **chair motivated** to use active learning techniques, but he was also able to **leverage local funding opportunities** to implement his ideal classroom. Beyond this material display of his interest in teaching, he has also helped shift the culture of the department. Christine recounted, "I will say that there has been a really big evolution over that time. So, he's the third chair that I think I've been through. And so it definitely has been, there were previous chairs who were really not very, they were still kind of part of the older generation where it's like, 'Research is the only thing that matters. Yeah. We have to teach our classes too, but.' I would say our current chair has been very transformative towards the department to also put more value on the teaching that we are doing. And it's not just like the throw off thing, it's like, no, this really does matter because it makes everything easier down the road. Like he's really stressing the relevance of advising…And you know, getting kids to graduation." The current **chair** has helped **develop a culture of valuing undergraduate teaching** in the department, placing emphasis on the importance of teaching. This excerpt also shows that for the chemistry department at Cedar University, teaching transformation was not always a top-down effort; past chairs have not all shared the commitment to teaching that the current chair holds.

Another aspect of the department **culture** is **sending their faculty to external professional development** around teaching. Christine shared how, "another colleague and I were actually sent to an active learning workshop run by NSF specifically for analytical chemistry. And so that's, and so [colleague] and I have brought back a lot of the stuff that we learned at that workshop and brought it back to the department. So that, we, that's how, what really influenced a lot of the changes that I made in the way that I taught [the intro to gen chem course]. So, and then, you know, talking to the department about, 'Oh, we learned this and this and this. And then is this something that you think you could use in your classroom? We found that it was really helpful.'" This excerpt illustrates the connection between culture and motivated people, displayed by the blue, leftward-pointing arrow in Fig. 3: an aspect of the department **culture, sending faculty to external professional development, supported** Christine and another **motivated faculty** member in **gaining knowledge** about active learning. They were then able to share what they learned with others in the department, **enhancing the culture of collaboration** around teaching (and illustrating the connection between motivated people and culture displayed by the red, rightward-facing arrow in the model).

The **culture** of supporting teaching extends to **how teaching is evaluated** in the chemistry department. As Christine explained, "The way that our departmental standards for tenure and stuff are set out, it allows the flexibility to try new things and actually encourages it even if you're going to, because you're always going to take a hit [in your student evaluation scores]. Until you figure, until you get it ironed out, um, and I would say that we, we welcome that." She describes **teaching evaluation policies** that are supportive of the uptake of active learning methods because they encourage instructors to experiment with teaching techniques in the classroom. Notably, Christopher who is pre-tenure relayed a very similar perspective to that of associate professor Christine. Christopher said, "I think also the senior colleagues have also understood that when you try a new teaching style, that students, um, we have student opinion questionnaires…can take a hit, especially the first time you do something. So I guess I'm trying to say is I don't, I don't think there's pressure to conform to one specific pedagogical strategy…the expectation is that we are trying to grow as educators and that we are finding strategies that are successful and successful based on having student feedback that suggests that, having, you know, also reflecting on what we've done, you know, not just, and also like informal feedback throughout the semester from the students, in addition to like the final feedback at the end of the semester." The teaching evaluation policies do not punish instructors for trying new pedagogy and in fact encourage **continual innovation** in the classroom with the expectation of growth and reflection.

In summary, the chemistry department at Cedar University has established a high level of active learning use in its introductory courses through the efforts of a constellation of motivated faculty who have developed a supportive teaching culture which in turn supports their individual work. While the current department chair is a strong advocate for active learning, the uptake of innovative pedagogies was generally not a top-down initiative. Individual faculty members have transformed their teaching, sometimes collaborating with peers to enact the change or supporting colleagues interested in adopting their teaching practices. These motivated faculty were also able to leverage local funding opportunities to support implementation of active learning. The CER presence in the department and the DBER presence campus-wide has helped enhance the culture supportive of teaching. Professional development supported by the department served to increase the teaching knowledge of motivated faculty, who then shared that knowledge with the rest of the department. Department structures, such as teaching evaluation policies, reinforced a culture of continual teaching innovation and allowed motivated faculty to continue to try new teaching techniques.

Discussion

The model of the characteristics of departments that are high users of active learning consists of four components, one outcome, and two feedback loops. The four components are motivated people, knowledge about teaching, opportunities, and cultures and structures that support active learning. In these departments, there are individuals motivated to increase active learning use in the introductory STEM courses, who have knowledge of research-based instructional strategies and are able to leverage a variety of opportunities to implement active learning instructional practices. The efforts of these people are enhanced by cultures and structures in their department and institution that are supportive of active learning and, in a positively reinforcing loop, these people act to enhance those very cultures and structures. The cycle between these components leads to high use of active learning in the introductory courses in these departments, and once active learning is implemented in these courses, that acts to reinforce the culture supportive of active learning.

The model is consistent with literature suggesting that motivated people with knowledge of good teaching practices are important for teaching change. For example, according to Huber and Hutchings (2021), an important contributor to departmental changes around teaching is an embedded educational expert. These embedded experts could be post docs, such as were used in the Wieman Science Education Initiative (Wieman et al., 2010) model of change, but they could also be hired into temporary faculty positions, or even permanent faculty positions (Huber & Hutchings, 2021). The latter are often known as Science Faculty with Education Specialties (Bush et al., 2008) or Discipline-Based Education Research (DBER) Faculty (Andrews et al., 2016; NRC, 2012). Relatedly, Denaro et al. (2022) studied the active learning practices of faculty in the University of California system, which has tenure-track positions for education-focused faculty. Faculty in this role still have a scholarship expectation, and many engage in DBER (Denaro et al., 2022). Examining faculty in STEM disciplines, Denaro et al. (2022) found that faculty in these teaching-focused roles were more likely to use active learning practices than research-focused tenure-track faculty. Indeed, half of the departments in our sample had a "motivated person" who was trained in discipline-based education research and/or currently conducting education research. Notably though, all departments in our sample had STEM faculty who were not education researchers but were still motivated and knowledgeable

of active learning. This suggests that having typical faculty (who are not education researchers) involved may be critical for department-wide adoption of active learning.

Motivated people are also needed to provide leadership in change efforts. Over three-quarters of the departments in our sample mentioned chairs that were supportive of teaching change. Involvement of people in leadership positions such as chairs and deans was also found to be an important factor in Feola et al.'s (2023) study of three institutional educational change efforts. Leaders do not have to hold official leadership titles; however. we saw a number of departments where change occurred in a grass-roots fashion rather than as a top-down effort from those in formal leadership positions. As McAlpin et al. (2022) describe, instructors who use active learning techniques are more likely to be asked by their colleagues to discuss teaching, and this can lead to their colleagues' adoption of active learning practices. Substantial literature suggests that a change effort with no leadership is not likely to be successful. For example, Huber and Hutchings (2021) found that the critical factor in successful departmental change was the way that department leaders set up conversations about student learning and supported community building within the department. Similarly, Elrod and Kezar (2016) highlight the importance of leadership in the change process. According to their model, leadership is necessary for starting the process.

The present study also adds to the literature demonstrating that departmental change requires changes in departmental and institutional culture and structures (Eckel & Kezar, 2003; Henderson et al., 2011; Reinholz & Andrews, 2020; Reinholz et al., 2019). Further, our model supports the findings that cultures and structures are changed iteratively through continual conversation and relationship building (Huber & Hutchings, 2021; Reinholz et al., 2019). Specifically, we found that conversation and connection among the people motivated to enact active learning helped develop and enhance a departmental culture supportive of active learning. Additionally, we found that cultures and structures supportive of active learning are not only important in and of themselves, but also are crucial because of the role they play in supporting and increasing the number of motivated people in a department.

The model we describe in this paper is perhaps most similar to the Four Frames model (Reinholz & Apkarian, 2018), but puts different emphasis on the factors it describes. Both models include the components of structures and people. What the Four Frames describes as symbols is embedded in what we call culture. Power is not a distinct component in our model as it is in the Four Frames, but power is somewhat incorporated in our motivated people factor which includes people from different hierarchical statuses. However, the models diverge in how they organize or frame the components, and the resulting emphasis on different factors. The Four Frames describes all four "frames" (structures, people, symbols, power) as ways to understand the culture—or, four interrelated components of culture. Thus, the framing is that culture is the most important thing in a change effort. In our model, culture is one of the several important things to pay attention to and we separate people from the culture (while still acknowledging the dynamic interplay between people and culture). Our model also highlights the roles of knowledge and opportunities, which are not prominent in the Four Frames model. Both models can inform the product (outcome) of a change effort, but depending on the situation and the way change agents conceptualize culture, one model may be a "better fit" in designing a theory of change for a given context.

The model of characteristics of departments that are high users of active learning has been corroborated in another context: physics teacher education programs. In her evaluation report, Chasteen (2021) adapted the model to describe the sustainability of physics teacher education programs in 16 physics departments that have received grants from the Physics Teacher Education Coalition (PhysTEC) to support physics teacher education. These grants were typically $300,000 over 3 years, plus a 3-year institutional match. Chasteen found that "site sustainability increased overall as more elements from the model were added." (Chasteen, 2021, p. 22). Sites that lacked motivated people or structures and cultures supportive of physics teacher education did not have sustained programs. Sites with mostly motivated people, but a lack of structures and cultures, had mixed results. The most successful sites were those with motivated people and both structures and cultures that interacted in a positive feedback loop to support physics teacher education. This provides evidence that the basic model developed in this study is applicable beyond the specific case of high active learning use in introductory courses. Future work should test the model in additional contexts to better understand the range of applicability.

Furthermore, the work of Chasteen (2021) also addresses one of our study limitations; namely, that we cannot say for certain whether the same set of characteristics in our model do not also appear in lower use departments. The results from Chasteen (2021) suggest that outcomes are decreased as the number of model components present decreases. While further research is needed, this provides some evidence that the characteristics identified in the model may actually lead to the outcome.

The model provides insight into what a STEM department could do to try and create a high level of active learning use in its courses. In describing the characteristics of departments that are high users of active learning, the model helps illustrate the desired outcome. This is useful for a department crafting its theory of change, needing to articulate how its planned interventions will lead to intended outcomes (Reinholz & Andrews, 2020). The departments with high use of active learning in our sample had all of the model components present and interacting synergistically, as depicted with the arrows in the model. This suggests that a change effort focused on only a subset of the components—for example, focusing solely on increasing motivated people, or providing opportunities—may not be successful.

In addition, while the model suggests that each of the components are necessary for high use of active learning in the department, we found that how each component is enacted can vary significantly. Thus, the specific details of each component found in this study (see examples in Table 3) should not be seen as a comprehensive list, but rather as a set of examples to spur thinking. Each department will have to identify for themselves how to best enact these components in their own setting.

The model further suggests that high use of active learning in a department develops over time, through iterative and positively reinforcing feedback loops. In most of the departments we studied, this positive feedback loop was enacted over many years or even decades and was not strategically planned from the start. Although further work is needed to verify this, it is likely that well planned change efforts could significantly reduce the time needed. For example, in her work with departments that were funded to improve physics teacher education, Chasteen (2021) found that a three-year external grant (often followed by a three-year institutional match) along with all model components present led to sustained improvements in teacher education. Thus, we suspect that 3–6 years may be a reasonable timeframe within which to think about creating meaningful and sustainable change.

It is also important to note that, while external funding may be helpful and may allow for faster change, it is not necessary for the implementation of active learning. Four of the 16 departments we studied indicated that they had external funding that contributed to their high use of active learning. The rest of the departments took advantage of opportunities (some funded, some not) internal to their institutions. Any opportunities that support the positive feedback loops depicted in the model are likely to pay dividends in the long run. This includes things such as hiring people who support the vision of active learning instruction, using graduation initiatives to advocate for research-based teaching practices, and participating in an institution-wide active learning initiative.

Limitations

This study and the resulting model have several important limitations that should be addressed in future work. The model developed in this study is based on data from high use of active learning departments. Thus, some of the features and processes that we identify in the model may also be present in departments with lower levels of use of active learning instruction in their introductory courses. Aligned with a grounded theory methodology, future work should iterate on the sampling used in the current study to include data from departments with low use of active learning, as well as departments where the four model components are present but there is not high use of active learning. This additional data collection could help refine and develop the model into a change theory (an empirically based and generalizable description of how change occurs (Reinholz & Andrews, 2020)).

In addition, the selection of departments with high use of active learning in the introductory courses (3 + instructors in the top quartile of their discipline and institution type in terms of percent class time students spend in non-lecture activities) was based on the self-reported practices by those instructors who chose to respond to the initial survey. Self-reported levels of use of active learning may vary from reality. To minimize this limitation, in the interviews we asked participants to describe their teaching practice and this helped us confirm that they actually were using the active learning techniques they had selected in our survey. More importantly, though, instructors who did not respond to the survey may have very different levels of use of active learning instruction in the introductory courses than those who did respond. In the interviews, we asked respondents how similar they felt their instruction was to others in the department. Except for those in very small departments, most often they indicated that they did not feel sufficiently knowledgeable about the instructional practices of more than a couple of their colleagues. However, we also asked them what they thought contributed to their department's high-use of active learning, and no participant objected to the description of their department as "high-use".

We also note that there was one department in our sample where all the elements of the model were present, but the connections between the factors (the cycle) was not clear based on the interviews we collected. There was no counterevidence in the interviews to suggest that the connections between factors did not exist as described in the model, but, unlike the other departments, we were not able to confirm the connections for this department. This could be due to the particular perspectives

and department knowledge of the two people we interviewed, or this may demonstrate that the model is not perfectly applicable to every high use of active learning department. We still are confident in the model because it explains well the other 15 departments in our analysis sample, but future work should test the model on additional departments to identify nuances in its applicability.

Finally, we only interviewed a maximum of two respondents in each department. Having two respondents afforded us the opportunity to do some level of triangulation, and there were usually many things that both respondents agreed on. However, in some cases, a particular aspect or characteristic of the department was only mentioned by one respondent. We did include these things in the model when they arose in multiple departments. There was only one example where respondents from the same department explicitly disagreed about the role of a factor on the teaching in the department. In that case, one interviewee said a commitment to teaching innovation was an important factor in hiring decisions, whereas the second interviewee said that a new faculty member was hired because they teach traditionally. We considered their statements in the context of their history and experience with the department as well as their consistency in perspectives shared throughout their interviews. We decided that hiring was an important factor for innovative teaching in that department because Interviewee Two actually provided support for that perspective as well– while they mentioned one person being hired because of their traditional teaching, they talked about multiple new faculty who are very interested in adopting active learning techniques.

Conclusions

Based on interviews with 27 instructors in 16 departments, we have developed a model that highlights the relevant characteristics of chemistry, math, and physics departments that have high use of active learning instruction in their introductory courses. According to this model, there are four main characteristics of such departments (motivated people, knowledge about teaching, opportunities, and cultures and structures that support active learning) and two positive feedback loops. There are two main take-away messages for those interested in promoting the use of active learning in their department. The first is that all four components are important. A weak or missing component could limit the desired outcome. The second is that desired outcomes are obtained and strengthened over time through two positive feedback loops. It is likely unrealistic to expect meaningful, sustainable change to occur in less than three years.

The model developed in this study can help academic departments and institutions attain greater use of active learning instructional strategies. Departments that are just starting out can use the model to strategically plan change efforts. The model suggests that all four components are necessary, but that each can be enacted in different ways. A diagnosis of the current state of the department with respect to the four components (and existing links between them) can help the department decide the desired outcomes of their change initiative and where to most effectively place their efforts.

Similarly, a department that is already engaged in an effort to increase the use of active learning instruction can use the model to review their efforts and identify components and connections that are either not enacted or that could be made more robust.

We also have evidence that this model can explain the success and lack of success of departmental efforts to improve physics teacher education (Chasteen, 2021). Thus, the basic model components and relationships may be applicable to a wider range of departmental outcomes than the high use of active learning instruction in introductory courses. This should be explored in future work.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40594-024-00470-x.

Additional file 1. Interview Protocol.

Additional file 2. Complete codebook.

Acknowledgements

We thank Annelise Roti Roti and the APS Creative Team for their assistance in creating the model figure (Fig. 1).

Author contributions

A.C.L. led data collection, analysis, and writing of this manuscript. C.H. was involved in study design, data collection, analysis, and was a major contributor in writing the manuscript. M.S. and M.D. were involved in study design, data collection, and analysis. C.M. participated in data analysis. N.A. was involved in study design, data collection, and consulted on analysis. J.R.R. and E.J. were involved in study design and consulted on analysis. All authors read and approved the final manuscript.

Funding

This material is based upon work supported by the National Science Foundation under Grant Nos. DUE 1726126 (J.R.R.), 2028134 (M.S.), 1726328 (C.H.), 1726042 (M.H.D.), and 1726281 (E.J.). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to confidentiality protection of research participants but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This research project received IRB approval from Western Michigan University Human Subjects Institutional Review Board.

Competing interests

One of the authors, M.S., is on the Editorial Board for this journal. An external evaluator for a program at A.C.L.'s place of employment has applied the model presented in this research article to explain the varied levels of success for members of the program (PhysTEC). A.C.L. is not currently involved in this program, but did consult on the program prior to her current employment, during the period when she was analyzing the data presented in this manuscript.

Author details

[1]American Physical Society, 1 Physics Ellipse, College Park, MD 20740-3844, USA. [2]Department of Physics, Mallinson Institute for Science Education, Center for Research on Instructional Change in Postsecondary Education, Western Michigan University, 1903 W. Michigan Ave., Kalamazoo, MI 49006-5444, USA. [3]Department of Chemistry, University of Virginia, Physical Life Sciences Building, 409 McCormick Road, Charlottesville, VA 22904-4319, USA. [4]The Evaluation Center, Western Michigan University, Kalamazoo, MI 49008-5237, USA. [5]School of Mathematical and Statistical Sciences, Arizona State University, P.O. Box 871804, Tempe, AZ 85287-1804, USA. [6]Department of Chemistry, University of South Florida, 4202 East Fowler Ave, Tampa, FL 33620, USA. [7]Department of Mathematics, Virginia Tech, 225 Stanger St, Blacksburg, VA 24061, USA.

Received: 13 June 2023 Accepted: 28 January 2024
Published online: 12 February 2024

References

AAAS. (2011). *Vision and change in undergraduate biology education: A call to action*. American Association for the Advancement of Science.

AACU. (2014). *Achieving systemic change: A sourcebook for advancing and funding undergraduate STEM education*. Association of American Colleges and Universities.

Andrews, T. C., Conaway, E. P., Zhao, J., & Dolan, E. L. (2016). Colleagues as change agents: How department networks and opinion leaders influence teaching at a single research university. *CBE—Life Sciences Education, 15*(2), ar15.

Apkarian, N., Henderson, C., Stains, M., Raker, J., Johnson, E., & Dancy, M. (2021). What really impacts the use of active learning in undergraduate STEM education? Results from a national survey of chemistry, mathematics, and physics instructors. *PLoS ONE, 16*(2), e0247544. https://doi.org/10.1371/journal.pone.0247544

Austin, A. E. (2011). *Promoting evidence-based change in undergraduate science education: A paper commissioned by the National Academies National Research Council Board on Science Education*. Washington, DC. https://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_072578.pdf

Bolman, L. G., & Deal, T. E. (2008). *Reframing organizations: Artistry, choice, and leadership*. Jossey-Bass.

Bush, S. D., Pelaez, N. J., Rudd, J. A., Stevens, M. T., Tanner, K. D., & Williams, K. S. (2008). Science faculty with education specialties. *Science, 322*(5909), 1795–1796.

Charmaz, K. (2006). *Constructing grounded theory* (1st ed.). SAGE Publications.

Chasteen, S. (2021). Summary report: 2021 Comprehensive II site sustainability evaluation study. https://cdn.sanity.io/files/4wurd6lm/production/cd51820663c37691557e926fde682633706b6a01.pdf

Corbo, J. C., Reinholz, D. L., Dancy, M. H., Deetz, S., & Finkelstein, N. (2016). Framework for transforming departmental culture to support educational innovation. *Physical Review Physics Education Research, 12*(1), 010113.

Creswell, J. W., & Poth, C. N. (2016). *Qualitative inquiry and research design: Choosing among five approaches*. Sage publications.

Denaro, K., Kranzfelder, P., Owens, M. T., Sato, B., Zuckerman, A. L., Hardesty, R. A., Signorini, A., Aebersold, A., Verma, M., & 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. https://doi.org/10.1186/s40594-022-00365-9

Eckel, P. D., & Kezar, A. J. (2003). *Taking the reins: Institutional transformation in higher education*. Praeger Publishers.

Elrod, S., & Kezar, A. (2016). *Increasing student success in STEM: A guide to systemic institutional change*. Association of American Colleges and Universities.

Feola, S., Lewis, J. E., McAlpin, J. D., et al. (2023). STEM education institutional change projects: Examining enacted approaches through the lens of the Four Categories of Change Strategies Model. *International Journal of STEM Education, 10*, 67. https://doi.org/10.1186/s40594-023-00458-z

Fisher, K. Q., & Henderson, C. (2018). Department-level instructional change: Comparing prescribed versus emergent strategies. *Cbelife Sciences Education, 17*(4), ar56.

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. https://doi.org/10.1073/pnas.1319030111

Gibson, B., & Hartman, J. (2013). *Rediscovering grounded theory*. Sage.

Glaser, B. G., & Strauss, A. L. (2017). *The discovery of grounded theory: Strategies for qualitative research*. Routledge.

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*, 952–984. https://doi.org/10.1002/tea.20439

Henderson, C., & Dancy, M. (2007). Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics. *Physical Review Special Topics: Physics Education Research, 3*(2), 020102. https://doi.org/10.1103/PhysRevSTPER.3.020102

Henderson, C., Finkelstein, N., & Beach, A. (2010). Beyond dissemination in college science teaching: An introduction to four core change strategies. *Journal of College Science Teaching, 39*(5), 18–25.

Huber, M. T., & Hutchings, P. (2021). Dynamics of departmental change: Lessons from a successful STEM teaching initiative. *Change: the Magazine of Higher Learning, 53*(5), 41–47. https://doi.org/10.1080/00091383.2021.1963154

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), 8. https://doi.org/10.1186/s40594-016-0042-3

Knight, P. T., & Trowler, P. R. (2000). Department-level cultures and the improvement of learning and teaching. *Studies in Higher Education, 25*(1), 69–83.

Kober, N. (2015). *Reaching students: What research says about effective instruction in undergraduate science and engineering*. Board on Science Education, Division of Behavioral and Social Sciences and Education. The National Academies Press. https://doi.org/10.17226/18687

Laursen, S., Andrews, T., Stains, M., Finelli, C. J., Borrego, M., McConnell, D., Johnson, E., Foote, K., Ruedi, B., and Smith, D. (2019) Levers for change: An assessment of progress on changing STEM instruction. *American Association for the Advancement of Science.* https://www.aaas.org/sites/default/files/2019-07/levers-for-change-WEB100_2019.pdf

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Sage Publications.

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. https://doi.org/10.1186/s40594-015-0026-8

McAlpin, J. D., Ziker, J. P., Skvoretz, J., Couch, B. A., Earl, B., Feola, S., Kelly Lane, A., Mertens, K., Prevost, L. B., Shadle, S., Stains, M., & 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. https://doi.org/10.1186/s40594-022-00364-w

National Academies of Sciences, Engineering, and Medicine. (2021). *Call to action for science education: Building opportunity for the future*. The National Academies Press. https://doi.org/10.17226/26152

National Research Council. (2012). *Discipline-based education research: Understanding and improving learning in undergraduate science and engineering*. The National Academies Press. https://doi.org/10.17226/13362

Ngai, C., Corbo, J. C., Falkenberg, K. L., Geanious, C., Pawlak, A., Pilgrim, M. E., Quan, G. M., Reinholz, D. L., Smith, C., & Wise, S. B. (2020). *Facilitating change in higher education: The Departmental Action Team model*. Glitter Cannon Press.

Otero, V., Pollock, S., & Finkelstein, N. (2010). A physics department's role in preparing physics teachers: The Colorado learning assistant model. *American Journal of Physics, 78*(11), 1218–1224.

Quan, G. M., Corbo, J. C., Finkelstein, N. D., Pawlak, A., Falkenberg, K., Geanious, C., Ngai, C., Smith, C., Wise, S., Pilgrim, M. E., & Reinholz, D. L. (2019).

Designing for institutional transformation: Six principles for department-level interventions. *Physical Review Physics Education Research, 15*(1), 010141.
Reinholz, D. L., & Andrews, T. C. (2020). Change theory and theory of change: What's the difference anyway? *International Journal of STEM Education, 7*, 2. https://doi.org/10.1186/s40594-020-0202-3
Reinholz, D. L., & Apkarian, N. (2018). Four frames for systemic change in STEM departments. *International Journal of STEM Education, 5*, 3. https://doi.org/10.1186/s40594-018-0103-x
Reinholz, D. L., Pilgrim, M. E., Corbo, J. C., & Finkelstein, N. (2019). Transforming undergraduate education from the middle out with departmental action teams. *Change: the Magazine of Higher Learning, 51*(5), 64–70.
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*(8), 1–13. https://doi.org/10.1186/s40594-017-0062-7
Stains, M., Harshman, J., Barker, M. K., Chasteen, S. V., Cole, R., DeChenne-Peters, S. E., et al. (2018). Anatomy of STEM teaching in North American universities. *Science, 359*(6383), 1468–1470.
Sturtevant, H., & Wheeler, L. (2019). The STEM Faculty Instructional Barriers and Identity Survey (FIBIS): Development and exploratory results. *International Journal of STEM Education, 6*(35), 1–22. https://doi.org/10.1186/s40594-019-0185-0
Vishnubhotla, M., Chowdhury, A., Apkarian, N., Johnson, E., Dancy, M., Henderson, C., Lau, A. C., Raker, J. R., & Stains, M. (2022). "I use IBL in this course" may say more about an instructor's beliefs than about their teaching. *International Journal of Research in Undergraduate Mathematics Education*. https://doi.org/10.1007/s40753-022-00186-9
Wieman, C., Perkins, K., & Gilbert, S. (2010). Transforming science education at large research universities: A case study in progress. *Change: the Magazine of Higher Learning, 42*(2), 6–14.
Yik, B. J., Raker, J. R., Apkarian, N., Stains, M., Henderson, C., Dancy, M. H., & Johnson, E. (2022a). Evaluating the impact of malleable factors on percent time lecturing in gateway chemistry, mathematics, and physics courses. *International Journal of STEM Education, 9*(15), 1–23. https://doi.org/10.1186/s40594-022-0033
Yik, B. J., Raker, J. R., Apkarian, N., Stains, M., Henderson, C., Dancy, M. H., & Johnson, E. (2022b). Association of malleable factors with adoption of research-based instructional strategies in introductory chemistry, mathematics, and physics. *Frontiers in Education, 7*, 1016415. https://doi.org/10.3389/feduc.2022.1016415

Publisher's Note