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Association of malleable factors with adoption of research-based instructional strategies in introductory chemistry, mathematics, and physics

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Active learning pedagogies are shown to enhance the outcomes of students, particularly in disciplines known for high attrition rates. Despite the demonstrated benefits of active learning, didactic lecture continues to predominate in science, technology, engineering, and mathematics (STEM) courses. Change agents and professional development programs have historically placed emphasis on develop–disseminate efforts for the adoption of research-based instructional strategies (RBIS). With numerous reported barriers and motivators for trying out and adopting active learning, it is unclear to what extent these factors are associated with adoption of RBIS and the effectiveness of change strategies. We present the results of a large-scale, survey-based study of introductory chemistry, mathematics, and physics instructors and their courses in the United States. Herein, we evaluate the association of 17 malleable factors with the tryout and adoption of RBIS. Multilevel logistic regression analyses suggest that several contextual, personal, and teacher thinking factors are associated with different stages of RBIS adoption. These results are also compared with analogous results evaluating the association of these factors with instructors' time spent lecturing. We offer actionable implications for change agents to provide targeted professional development programming and for institutional leaders to influence the adoption of active learning pedagogies in introductory STEM courses.

KEYWORDS

research-based instructional strategies, evidence-based instructional practices, institutional change, active learning, contextual factors, personal factors, beliefs about teaching

Introduction

Research-based instructional strategies (RBIS; see Dean et al., 2012) and evidence-based instructional practices (EBIPs; see Stains and Vickrey, 2017) are similarly used labels for instructional practices with a basis in educational research, including active learning. Active learning in undergraduate science, technology, engineering, and mathematics (STEM) courses has been demonstrated to enhance student outcomes (Springer et al., 1999; Lorenzo et al., 2006; Haak et al., 2011; Ruiz-Primo et al., 2011; Freeman et al., 2014; Rahman and Lewis, 2019; Theobald et al., 2020). Compared to traditional lecture-based courses, active learning courses are associated with increased achievement across all STEM disciplines (Freeman et al., 2014). Notably, studies also show an increase in achievement outcomes for minoritized populations in active learning courses (Lorenzo et al., 2006; Kogan and Laursen, 2014; Synder et al., 2016; Ballen et al., 2017; Deri et al., 2018; Roberts et al., 2018; Stanich et al., 2018; Theobald et al., 2020). For college students enrolled at two-year institutions and community colleges, active learning has been shown to contribute to increased graduation rates (Riedl et al., 2021) and transfer rates (Wang et al., 2017). In this paper, we refer to these teaching practices as RBIS, which can include, but are not limited to, think-pair-share, small group work, peer instruction, peer-led team learning, flipped classroom, and just-in-time-teaching (for more comprehensive lists of RBIS, see: Henderson and Dancy, 2009; Borrego et al., 2013; Baker et al., 2014). These strategies have foundations in the education research literature, contrast with didactic lecture, and engage students in the learning process in lieu of passively listening to an instructor (Bonwell and Eison, 1991).

Although active learning pedagogies undoubtedly have established benefits in STEM, lecture-based pedagogical approaches remain dominant (Stains et al., 2018). The research literature suggests the prominence of lecture-oriented pedagogies may be a result of institutional failure to normalize use of RBIS (Henderson and Dancy, 2007; Shadle et al., 2017), failure to implement faculty incentives or rewards for using student-centered pedagogical techniques (Michael, 2007; Brownell and Tanner, 2012; Shadle et al., 2017), and failure to combat student resistance to instructional changes (Henderson and Dancy, 2007; Michael, 2007; Shadle et al., 2017), among the plethora of reasons.

In addition to these barriers, instructors have expressed feeling unprepared for changing the way they teach (Andrews and Lemons, 2015; Bathgate et al., 2019a). Foremost, instructors may have little or no knowledge about and awareness of alternatives to traditional lecturing, i.e., using RBIS (Hativa, 1995; Miller et al., 2000; Luft et al., 2004; Walczyk et al., 2007; Yarnall et al., 2007; Winter et al., 2012). Once aware, though, of RBIS and active learning strategies, instructors may lack opportunities to try out these new strategies (Handelsman et al., 2004; Ebert-May et al., 2011) or may be unconvinced that these strategies are more effective than lecturing (Miller et al., 2000; Yarnall et al., 2007; Winter et al., 2012).

While meta-analytic work by Freeman et al. (2014) and Theobald et al. (2020) have noted the importance of active learning in STEM education, parallel multidisciplinary studies of malleable factors (i.e., something that can be changed and altered) related to the adoption of such active learning pedagogies in postsecondary STEM courses are largely absent from and needed in the research literature (National Research Council (NRC), 2012; American Association for the Advancement of Science (AAAS), 2019). To date, only one study at such a level (Yik et al., 2022) details the association of malleable factors with the adoption of active learning in multiple STEM disciplines. In Yik et al. (2022), as with this study, we focus on introductory chemistry, mathematics, and physics, which are high-enrollment courses serving a large number of students [President's Council of Advisors on Science and Technology (PCAST), 2012] and are barriers for students not finishing STEM degrees (Seymour and Hewitt, 1997; Koch, 2017; Seymour and Hunter, 2019). In Yik et al. (2022), we evaluated 17 malleable factors that have been reported in the research literature to be associated with percent lecturing (i.e., time not spent using active learning strategies) in gateway STEM courses. However, another measure of active learning is stage of adoption of RBIS. While knowing the amount of time lecturing allows for conclusions about the degree of student-centered learning, it does not provide information about an instructor's awareness about RBIS, time spent learning about and readiness to tryout RBIS, and adoption of RBIS in their courses (Landrum et al., 2017); instructors' needs are different based on their awareness, tryout, and adoption of RBIS (Viskupic et al., 2022). This study will add to the research literature by quantifying the association of malleable factors on the adoption of RBIS in introductory chemistry, mathematics, and physics courses. Evaluation of these malleable factors on RBIS adoption allows for comparisons with a previous variable, i.e., percent time lecturing (Yik et al., 2022), on the effects of different aspects of active learning, and thus, yields recommendations for the adoption of RBIS to promote active learning in introductory STEM courses.

In the context of introductory chemistry, mathematics, and physics courses, two research questions guide this study:

1. To what extent are malleable contextual, personal, and teacher thinking factors associated with the stages of RBIS adoption?
2. How do the association of malleable contextual, personal, and teacher thinking factors with the stages of RBIS adoption compare with percent lecturing?

Conceptual frameworks

Research on barriers and driving forces for the adoption of teaching strategies informed the selection of malleable factors that were previously modeled (see Yik et al., 2022) and are modeled in this study. Researchers (e.g., Gess-Newsome et al., 2003; Dancy and Henderson, 2010; Andrews and Lemons, 2015; Lund and Stains, 2015; Sturtevant and Wheeler, 2019) have described a number of contextual, personal, and belief factors that influence instructors' pedagogical decisions. Through a comprehensive review of the literature, Woodbury and Gess-Newsome (2002) developed the Teacher-Centered Systemic Reform (TCSR) model to understand how classrooms change due to reform initiatives; this framework was later modified to better suit the higher education system (Gess-Newsome et al., 2003). The TCSR model focuses on teachers' thinking and practices as the origin for change that happen within the classroom inside the context of a larger university system (Gess-Newsome et al., 2003). In a university context, the TCSR framework is comprised of three broad categories: contextual factors (e.g., institution type, discipline, and class size), personal factors (e.g., extent of teacher preparation and teaching-related professional development), and teacher thinking factors (e.g., knowledge about teaching and dissatisfaction with current teaching practices); these categories were used to situate the malleable factors modeled in our prior study (Yik et al., 2022). Our current study also aims to evaluate the association of these same malleable factors with the adoption of RBIS when institutional and disciplinary differences are accounted for. Non-malleable factors (e.g., race/ethnicity) are not included because they do not provide actionable implications. While this study focuses on introductory chemistry, mathematics, and physics courses, we include malleable factors that have been reported to be related to the adoption of teaching strategies in the broader STEM education literature. While there may be some disciplinary differences and STEM disciplines differ in the amount of research literature in this area, these malleable factors can be assumed to affect all STEM disciplines to an extent (Lund and Stains, 2015). A summary of the malleable factors, logic for inclusion in this study, and relevant literature citations are given in Table 1.

Dormant's (2011) Chocolate Model of Change, also known as the CACAO model, has been used to conceptualize institutional change in STEM education (Marker et al., 2015; Landrum et al., 2017; Shadle et al., 2017; Earl et al., 2020; Pilgrim et al., 2020; Salomone et al., 2020; McAlpin et al., 2022; Viskupic et al., 2022). The CACAO model is organized around four dimensions: (1) Change, (2) Adopters, (3) Change Agents, and (4) Organization (Dormant, 2011). *Change* is a new idea, process, or system that you want a group of people to accept (e.g., adoption of RBIS). *Adopters* are the group of people that is targeted to adopt the change (e.g., instructors of introductory STEM courses). *Change agents* are the people and team trying to enact change (e.g., administrators, educational policy makers, educational researchers, instructional designers). The *organization* encompasses the change, adopters, and change agents. Organizational contexts and influences affect how change agents lead change initiatives in hopes that adopters accept or implement the change. In a higher education setting, departments, colleges/schools, and the institution all have influence on individuals' beliefs and behaviors, which can influence social norms and thus change in an organization.

In operationalizing the dimensions of the CACAO model, we investigate *change* as the state of teaching transformations through the uptake of RBIS, *adopters* as the STEM instructors that amend their instruction to include using RBIS in their teaching practices, *change agents* as the individuals advocating for adoption of RBIS, and the *organization* as the members of higher education institutions. For *adopters*, Dormant (2011) outlines five stages of adoption: (1) awareness, (2) curiosity, (3) mental tryout, (4) hands-on tryout, and (5) adoption.

The TCSR framework and the CACAO model work in tandem to understand institutional change. The CACAO model is designed to aid *organizational* (i.e., institutional) *change agents* (i.e., change practitioners and leaders) to understand dimensions of *change* (Dormant, 2011); in this study, we focus on malleable factors that influence the dimensions of change. The TCSR framework focuses on teachers' beliefs, which influence teacher practices, as the center for change that occurs within the institution (Gess-Newsome et al., 2003); contextual factors, personal factors, and teacher thinking factors are described as components in this larger institutional change context. Factors modeled in this study are situated within the components TCSR framework and influence the *adopter's* (i.e., instructor's) uptake of RBIS (i.e., the *change*) within the organization (i.e., *institution*). Evaluation of these malleable factors allows for insights and recommendations for *change agents* to provide opportunities that meet the needs of adopters in the different stages of adoption. Therefore, the TCSR and CACAO models are congruent and complementary, and together, situate our study.

Materials and methods

Respondents

Target courses are general chemistry, single-variable calculus, and quantitative-based introductory physics. Target institutions are two-year associate-degree granting institutions in the United States that offer all three of these target courses, and four-year bachelor's and/or graduate degree-granting institutions that have conferred at least one bachelor's degree in all three disciplines (i.e., chemistry, mathematics, and physics) between 2011 and 2016 as recorded by the National Center for Education Statistics' Integrated Postsecondary Education Data System. Target participants are primary instructors for one of the three target courses that was not taught exclusively online in the 2017–2018 or 2018–2019 academic years in the United States.

A database of the target instructors was assembled through stratified consensus sampling centered around target institution type; the objective was to construct a representative sample of two-year institutions, four-year institutions, and universities to capture the different types of degree-granting institutions (i.e., associate, bachelor's, and graduate, respectively). The database was

TABLE 1 Malleable factors included in this study situated within the TCSR framework and hypotheses about how factors impact the adoption of RBIS with relevant citations.

Malleable factor	Logic for inclusion	Relevant citations that describe barriers or driving forces for adoption of active learning
Department characteristics		
Discipline	Teaching practices differ between STEM disciplines.	Fairweather and Rhoads (1995), Singer (1996), Lindblom-Ylänne et al. (2006), Hora and Anderson (2012), Lund and Stains (2015), Matz et al. (2018), Stains et al. (2018), Reinholz et al. (2019), and Denaro et al. (2022)
Highest degree awarded	Two-year colleges are commonly thought of as being more teaching-focused, whereas universities are thought of as being more research-focused; this is a proxy for the magnitude of focus on teaching vs. research.	Grubb (2002), Cox et al. (2011), Brownell and Tanner (2012), Srinivasan et al. (2018), and Riihimaki and Viskupic (2020)
Department appointment expectations		
Teaching load	Heavy teaching loads have been reported to be one of the biggest barriers to implementing RBIS.	Henderson and Dancy (2007) and Hora (2012)
Tenure status	Tenure-track and tenured faculty members have to distribute time and energy between teaching and research and implementing RBIS can be time consuming; RBIS adoption has been shown to be lower for instructors without opportunity for tenure.	Price and Cotten (2006), Fairweather (2008), Dancy and Henderson (2010), Hora (2012), Budd et al. (2013), Lund et al. (2015), Landrum et al. (2017), Shadle et al. (2017), Reinholz et al. (2019), Indorf et al. (2021), and Raker et al. (2021)
Student evaluations of teaching	Student evaluations can be influential in tenure or promotion and instructors may not want to upset students by using unfamiliar teaching strategies at risk of receiving undesirable evaluations.	Hattie and Marsh (1996), Anderson (2002), Michael (2007), Walczyk et al. (2007), Zabaleta (2007), Henderson et al. (2014), Erdmann et al. (2020), and Soto and Marzocchi (2021)
Assessment of teaching performance	Perceived norms to provide student-centered teaching may pressure use of RBIS to obtain tenure or promotion, but departmental reward systems vary widely and commonly do not value teaching.	Prosser and Trigwell (1997), Henderson and Dancy (2007) Michael (2007), Walczyk et al. (2007), Seymour et al. (2011), Brownell and Tanner (2012), Hora and Anderson (2012), Henderson et al. (2014), Lund and Stains (2015), Elrod and Kezar (2017), Johnson et al. (2018), and Sturtevant and Wheeler (2019)
Classroom contextual		
Class size	Larger class sizes have higher amounts of didactic lecture and thus have student engagement.	Prosser and Trigwell (1997), Henderson and Dancy (2007), Hora and Anderson (2012), Smith et al. (2014), Bressoud and Rasmussen (2015), Lund et al. (2015), Lund and Stains (2015), Shadle et al. (2017), Sturtevant and Wheeler (2019), Borda et al. (2020), Apkarian et al. (2021), Denaro et al. (2022), and Yik et al. (2022)
Classroom setup	Large lecture halls with fixed seats make it more difficult to implement RBIS that focus on student interactions, whereas tables and moveable desks help alleviate this burden.	Henderson and Dancy (2007), Michael (2007), Lund et al. (2015), Lund and Stains (2015), Shadle et al. (2017), Tharayil et al. (2018), Sturtevant and Wheeler (2019), Borda et al. (2020), Riihimaki and Viskupic (2020), and Johnson et al. (2021)
Class size × classroom setup	RBIS can be effectively implemented with large class sizes if the classroom layout is conducive to group work and engagement.	Cotner et al. (2013), Lund and Stains (2015), Talbert and Mor-Avi (2019), and Yik et al. (2022)
Decision making	Co-teaching or coordinating courses allows for collaboration and shared ideas and beliefs among instructors; course coordinators can discuss pedagogical strategies with instructors of individual course sections.	Marbach-Ad et al. (2007), Henderson et al. (2009), Marbach-Ad et al. (2014), Rasmussen et al. (2014), Bressoud and Rasmussen (2015), Rasmussen and Ellis (2015), Reinholz and Apkarian (2018), Rasmussen et al. (2019), Bazett and Clough (2021), Carney et al. (2021), Dunnigan and Halcrow (2021), Golnabi et al. (2021), Mingus and Koelling (2021), and Villalobos et al. (2021)

(Continued)

TABLE 1 (Continued)

Malleable factor	Logic for inclusion	Relevant citations that describe barriers or driving forces for adoption of active learning
Personal factors		
RBIS use as a student	Instructors reflect on their own experiences as a student when deciding how to teach.	Oleson and Hora (2014), Lund and Stains (2015), and Fukawa-Connelly et al. (2016)
Scholarship of teaching and learning (SOTL)	Instructors can reflect upon their teaching practices which may lead into conducting or participating in SOTL or discipline-based education research (DBER); this engagement has been shown to lead to more student-centered teaching practices.	Henderson et al. (2011), Henderson et al. (2012), Henderson et al. (2017), Pelletreau et al. (2018), Dancy et al. (2019), Tomkin et al. (2019), and Benabentos et al. (2021)
Teaching-focused coursework	Doctoral and postdoctoral training and coursework cover a variety of topics, such as learning theory, effective practices, and instructional design, which provide instructors a foundation for informed teaching decisions.	Windschitl and Sahl (2002), Lotter et al. (2007), Southerland et al. (2011a), and Hora (2012)
Teaching-related workshops	Workshops disseminate new teaching pedagogies and can give instructors first-hand experience with RBIS.	Landis et al. (1998), Clark et al. (2002), Peace et al. (2002), Burke et al. (2004), Lotter et al. (2007), Manduca et al. (2010), Murray et al. (2011), Lund and Stains (2015), Fukawa-Connelly et al. (2016), Stegall et al. (2016), Manduca et al. (2017), Stains et al. (2018), Viskupic et al. (2019), Houseknecht et al. (2020), Riihimaki and Viskupic (2020), and Viskupic et al. (2022)
Teaching-related new faculty experiences	Experiences and workshops for new faculty members spread awareness and advocate for the adoption of RBIS.	Wood and Gentile (2003), Handelsman et al. (2004), Henderson (2008), Ebert-May et al. (2011), Henderson et al. (2012), Baker et al. (2014), Ebert-May et al. (2015), Stains et al. (2015), Derting et al. (2016), Beane et al. (2020), and Emery et al. (2021)
Teacher thinking		
Growth mindset	Instructors holding a growth mindset have been reported to use more student-centered approaches.	Rattan et al. (2012), Aragón et al. (2018), Johnson et al. (2018), Bathgate et al. (2019a), Canning et al. (2019), Ferrare (2019), and Yik et al. (2022)
Satisfaction with student learning	Dissatisfaction with current student learning or belief that students may learn better with alternative pedagogies may spur a revision of teaching and result in the adoption of new teaching strategies.	Feldman (2000), Windschitl and Sahl (2002), Gess-Newsome et al. (2003), Lotter et al. (2007), Southerland et al. (2011a,b), Bauer et al. (2013), Andrews and Lemons (2015), Gibbons et al. (2018), Erdmann et al. (2020), and Riihimaki and Viskupic (2020)

constructed by the American Institute of Physics Statistical Research Center using publicly available online information and by contacting department chairs at the target institutions. The database contains 18,337 instructors that have met these criteria and is comprised of 8,933 instructors at two-year associate-degree granting institutions and 9,404 instructors at four-year bachelor's and/or graduate degree-granting institutions.

Data collection

Previous large-scale studies in postsecondary chemistry (Gibbons et al., 2018; Stains et al., 2018), mathematics (Johnson et al., 2018; Apkarian et al., 2019), and physics (Henderson and Dancy, 2009; Walter et al., 2016, 2021) informed the development of the survey instrument. The survey is comprised of five main elements: (1) course context, (2) instructional practices, (3) awareness and usage of active learning instructional techniques, (4) perceptions, beliefs, and attitudes related to students, learning, and departmental context, and (5) personal demographics and experience. Previous instruments and scales with reliability and validity evidence were used where applicable, e.g., mindset (Dweck et al., 1995) and the EBIP Adoption scale (Landrum et al., 2017).

Survey instrument data were collected by the American Institute of Physics Statistical Research Center between March–May 2019 with approval from the Western Michigan University Institutional Review Board (application no. 17-06-10); informed consent was obtained digitally. Survey respondents included 3,769 instructors (20.5% unit response rate) consisting of 1,244

TABLE 2 Table of respondents by institution type, discipline, and academic rank.

Group	Count	Proportion	Group	Count	Proportion
Institution type			**Academic rank**		
University (UNI)	946	0.41	Professor	760	0.33
Predominantly undergraduate institution (PUI)	758	0.33	Associate professor	553	0.24
Two-year college (TYC)	599	0.26	Assistant professor	440	0.19
Total	2,303		Lecturer	548	0.24
Discipline			Visiting	2	< 0.01
Chemistry	768	0.33	*Total*	2,303	
Mathematics	751	0.33			
Physics	784	0.34			
Total	2,303				

chemistry, 1,349 mathematics, and 1,176 physics instructors; there were 1,099 instructors at two-year institutions and 2,670 instructors at four-year institutions. A total of 1,466 respondents were removed from this analysis due to incomplete responses for all the survey items used in the construction of the multilevel models. This resulted in the study sample of 2,303 respondents including 768 chemistry, 751 mathematics, and 784 physics instructors from 1,371 departments at 741 institutions; of these 2,303 instructors, 599 instructors are at two-year institutions and 1,704 instructors are at four-year institutions. Table 2 presents the institution type, discipline, and academic rank of the respondents included in this study; the group proportions of the respondents included in this study mirror that of the full survey sample as previously reported (Apkarian et al., 2021), and thus, can be considered as representative sample of the target population.

A full list of survey items and their coding used in this study can be found in our previous work (see Yik et al., 2022). The RBIS Adoption Scale (described below) resulted in the binary outcome variables used in the multilevel logistic regression models (described below). Factors used in this survey are described above in Table 1.

Respondents were classified by their discipline (reference: mathematics), highest degree offered by their department (reference: associate degree), and tenure status (reference: instructors with no opportunity to earn tenure). Respondents were asked about their class size; teaching load; role of student evaluations of teaching in decisions of review, promotion, or tenure; role of assessment of teaching performance in decisions of review, promotion, or tenure; growth mindset; and satisfaction with student learning. Ordinal scales for each of these variables are described in the Results (Table 3, below), with the exception of student evaluation of teaching (role of student evaluation of teaching in review, promotion, or tenure compared to other measures: 0 = not used, 1 = less weight, 2 = equal weight, 3 = more weight, 4 = only used; reference: not used). Class size is grand-median centered at 30–39 students. Growth mindset is the average of three items on a six-point Likert scale (Dweck et al., 1995); items were reverse-coded, and values were centered at the middle of the scale. Satisfaction of student learning is a single item on a five-point Likert scale (very satisfied to very satisfied) and values were centered at the middle of the scale.

Respondents were also asked about teaching experiences: decision making authority in their course (i.e., respondent has sole decision-making authority or is in collaboration with others to make decisions), previous RBIS use in courses when then were a student, participation in the scholarship of teaching and learning, enrollment in teaching-focused coursework, participation in teaching-related workshops, and in teaching-related new faculty experiences; these are all binary variables (yes/no; except decision making, reference: sole decision-making authority). Additionally, respondents were asked about their overall time spent lecturing which is defined as the overall percent of time during regular class meetings that students spend listening to the instructor lecture or solve problems.

Research-based instructional strategies adoption scale

The RBIS Adoption Scale is an adaption of the EBIP Adoption Scale (Landrum et al., 2017); the sole difference is in wording of the instrument where "EBIP" is replaced by "RBIS" (Table 4). This instrument contains six items to be used as a Guttman scale with 'yes'/'no' responses. Guttman scales are unidimensional (i.e., is a measure of a single construct: degree of RBIS adoption), ordinal (i.e., items are ordered from the "least agreement" statement to the "most agreement" statement), and deterministic (i.e., results are analyzed based on the last statement the respondent agreed with; Guttman, 1944).

Guttman scales are self-scoring and is indicated when the response pattern changes from an agreement ('yes') to disagreement ('no'). Deviations from this pattern, such as an agreement to a later item after a disagreement on an earlier item, indicate a lack of reliability of the scale and unidimensional measure of the construct. Four statistical measures characterize the quality of responses when using a Guttman scale: coefficient of reproducibility (CR), minimal marginal reproducibility

(MMR), percent improvement (PI), and coefficient of scalability (CS; McIver and Carmines, 1981).

Together, the CR, MMR, PI, and CS aid in evaluating the reliability and unidimensionality of a Guttman scale (McIver and Carmines, 1981). First, the CR is a measure of the reliability of a Guttman scale and describes the proportion of differences between the observed and expected response pattern (Guttman, 1944). One issue with the CR is its sensitivity to extreme marginal distributions; in other words, if there are extreme patterns of responses or if respondents respond with extreme patterns, such as answering all scale items with the response 'yes' (Menzel, 1953; Guest, 2000). Second, the MMR reflects the reproducibility of the items based on the marginal distribution of the items; the value of MMR is the smallest value of CR that is possible given the observed proportion of agreement and disagreement responses for the items (Sudweeks, 2018). Third, PI is the difference between CR and MMR and reflects the improvement due to item ordering (McIver and Carmines, 1981). Finally, the CS is a measure of the predictability of the scale, or the proportion of responses that can be correctly predicted from the row and column marginals, and was introduced to combat artificially high CR (Menzel, 1953; Guest, 2000).

To demonstrate evidence of reliability and unidimensionality of the RBIS Adoption Scale, CR, MMR, PI, and CS values are calculated for the survey sample and for each discipline (i.e., chemistry, mathematics, and physics). For all data used in this study, every respondent provided full responses for the RBIS Adoption Scale (i.e., no items were left blank). Responses were ordered, and scale errors and marginal errors were calculated using the Goodenough–Edwards method (Goodenough, 1955; Edwards, 1957) to compute CR, PI, MMR, and CS values (Guest, 2000; Aiken and Groth-Marnat, 2006). For evidence of unidimensionality in a Guttman scale, CR > 0.90 and CS > 0.60 (Menzel, 1953; Guest, 2000; Aiken and Groth-Marnat, 2006; Abdi, 2010) are recommended standards along with lower MMR and larger PI values. The RBIS Adoption Scale demonstrates acceptable reliability for the study sample and three STEM disciplines that comprise the sample (Table 5).

Multilevel modeling

Models were constructed using the melogit package in Stata version 17 (StataCorp, 2021) using mean and variance adaptive Gauss–Hermite quadrature (mvaghermite) integration with seven integration points. Predictor variables used in these models (see Table 1, above, and Table 3, below) have been previously reported (Yik et al., 2022) through a review of the research literature on malleable factors that affect the uptake of active learning strategies from a variety of STEM disciplines.

Multilevel models are advantageous when considering that participants are not independent from one another as they can be grouped by department or institutions, and thus, violate the assumption that observations are independent (Raudenbush and Bryk, 2002; Snijders and Bosker, 2012). Herein, multilevel regression models are used to explain two outcomes: RBIS tryout (i.e., Tryout Model) and RBIS adoption (i.e., Adoption Model). In the EBIP Adoption Scale by Landrum et al. (2017), each item is mapped onto one of the CACAO adoption stages (Dormant, 2011); in this study, we combine the mental tryout and hands-on tryout stages into single stage, *tryout* (see Table 4, above). Strategies suggested by the CACAO model for mental tryout include demonstrating examples of change and highlighting success, and strategies suggested for hands-on tryout include providing training, information, and resources (Dormant, 2011). We combine the two tryout stages because strategies are commonly employed together in teaching-related workshops and experiences (Henderson, 2008; Ebert-May et al., 2011; Baker et al., 2014), and we also combine the three distinct adoption stages because instructors in these later stages have been reported to share similar characteristics and teaching practices (Viskupic et al., 2022). The distribution of RBIS awareness, tryout, and adoption of the respondents in this study is given in Table 6.

Two multilevel logistic regression models are used to evaluate the association of the 17 malleable factors with RBIS tryout and RBIS adoption. Two models are used to distinguish between awareness and tryout (i.e., Tryout Model), and also, tryout and adoption (i.e., Adoption Model). We differentiate the two multilevel logistic regression models into what could be a single multinomial logistic regression model; however, this would result in a set of two different regression coefficients from a reference stage of adoption. A single multilevel ordinal logistic regression model could also be used to model the data, but this model assumes that the odds between each of the adoption stages are equivalent and proportional. Previous work has demonstrated that the needs of instructors are different depending on what stage of adoption they are at (Viskupic et al., 2022). For more parsimonious and interpretable regression coefficients from which we can provide recommendations to change agents, we therefore model two different outcomes (i.e., tryout and adoption) using two multilevel logistic regression models.

Two multilevel models are reported herein: the Tryout Model and Adoption Model. The Tryout Model includes sample of 1,079 respondents including 360 chemistry, 430 mathematics, and 289 physics instructors from 826 departments at 579 institutions; of these 1,079 instructors, 327 instructors are at two-year institutions and 752 instructors are at four-year institutions. The Adoption Model includes sample of 1,757 respondents including 591 chemistry, 501 mathematics, and 665 physics instructors from 1,118 departments at 663 institutions; of these 1,757 instructors, 419 instructors are at two-year institutions and 1,338 instructors are at four-year institutions.

The two multilevel models in this study are three-level models that are used to evaluate the association of malleable factors on the stages of RBIS adoption in introductory chemistry, mathematics, and physics. The intraclass correlation coefficient (ICC) is an index of the proportion of variance in the outcome variable that is explained by groups or clusters, and is the ratio of the between group variance and

TABLE 3 Factors associated with RBIS Tryout and Adoption.

Factor	RBIS Tryout			RBIS Adoption		
	OR	SE	*p*	OR	SE	*p*
Department-level factors (level 2)						
Chemistry	0.92	0.20	0.708	1.28	0.19	0.112
Physics	2.13	0.47	0.001	2.06	0.31	<0.001
Bachelor's program	1.02	0.26	0.950	1.14	0.19	0.436
Graduate program	0.47	0.14	0.009	1.21	0.24	0.327
Instructor-level factors (level 1)						
Teaching load	1.16	0.09	0.069	0.94	0.05	0.300
Tenured faculty	1.17	0.24	0.445	0.81	0.11	0.125
Tenure-track faculty	0.92	0.26	0.761	0.96	0.18	0.814
Student evaluation of teaching	1.06	0.09	0.457	0.93	0.06	0.243
Assessment of teaching performance[a,b]	1.07	0.11	0.510			
= +1 (not influential)				1.23	0.09	0.003
= +2 (somewhat influential)				1.51	0.10	
= +3 (influential)				1.85	0.13	
= +4 (very influential)				2.28	0.16	
Class size[a,c]						
= −2 (2–19 students)	0.34	0.03		0.67	0.04	
= −1 (20–29 students)	0.59	0.05		0.82	0.05	
= +1 (40–59 students)	1.71	0.14	<0.001	1.22	0.07	0.001
= +2 (60–99 students)	2.92	0.25		1.50	0.09	
= +3 (100+ students)	4.98	0.42		1.84	0.11	
Classroom setup[c]	0.95	0.24	0.839	2.29	0.53	<0.001
Class size × classroom setup[a,b,c]				0.97	0.08	0.685
= −2 (2–19 students)	0.17	0.02				
= −1 (20–29 students)	0.40	0.05				
= +1 (40–59 students)	2.23	0.27	0.007			
= +2 (60–99 students)	5.25	0.63				
= +3 (100+ students)	12.26	1.45				
Decision making	1.59	0.41	0.070	0.87	0.11	0.135
RBIS use as a student	6.34	2.72	<0.001	2.15	0.38	<0.001
Scholarship of teaching and learning	1.01	0.20	0.937	2.25	0.28	<0.001
Teaching-focused coursework	0.88	0.16	0.458	1.21	0.15	0.128
Teaching-related workshops	4.85	1.33	<0.001	1.46	0.34	0.105
Teaching-related new faculty experiences	1.07	0.19	0.709	1.51	0.19	0.001
Growth mindset[a,b]	1.15	0.08	0.055			
= −2.5 (strong fixed mindset)				0.51	0.03	
= −1.5 (moderate fixed mindset)				0.66	0.04	
= −0.5 (slight fixed mindset)				0.87	0.05	
= +0.5 (slight growth mindset)				1.15	0.06	<0.001
= +1.5 (moderate growth mindset)				1.50	0.08	
= +2.5 (strong growth mindset)				1.97	0.10	
Satisfaction with student learning[a]						
= −2 (very dissatisfied)	1.32	0.13		0.58	0.04	
= −1 (dissatisfied)	1.15	0.11		0.76	0.05	
= +1 (satisfied)	0.87	0.09	<0.001	1.31	0.09	<0.001
= +2 (very satisfied)	0.76	0.08		1.73	0.12	

[a]Ordinal variable; *p*-values are omitted for additional ordinal levels.
[b]Not statistically significant variable; odds ratios are omitted for ordinal levels.
[c]Variable with interaction effect; variable should only be interpreted if the other variable is held constant; the interaction effect odds ratio accounts for the interaction effect and the individual fixed effects.

TABLE 4 RBIS Adoption Scale with associated CACAO stage of adoption.

RBIS Adoption Scale item	Score (number of '*yes*' responses)	CACAO Change model (Dormant, 2011)	Modified CACAO change model (this work)
	0	Awareness	Awareness
Prior to this survey, I already knew about RBIS.	1	Awareness	Awareness
I have thought about how to implement RBIS in my courses.	2	Mental Tryout	Tryout
I have spent time learning about RBIS and I am prepared to use them.	3	Hands-on Tryout	Tryout
I consistently use RBIS in my courses.	4	Adoption	Adoption
I consistently use RBIS and I continue to learn about and experiment with new RBIS.	5	Adoption	Adoption
I have evidence that my teaching has improved since I started using RBIS.	6	Adoption	Adoption

the total variance (Raudenbush and Bryk, 2002; Snijders and Bosker, 2012). Calculations for ICC values were performed as outlined in Liu (2015). The unconditional Tryout Model has an ICC of 0.11 for level 2 (department) and an ICC of 0.08 for level 3 (institution), meaning roughly, 11% of the variation in the outcome variable (i.e., stage of adoption: awareness or tryout) is accounted for by nesting instructors within departments and 8% of the variation in the outcome variable is accounted for by nesting departments within institutions. The unconditional Adoption Model has an ICC of 0.08 for level 2 and 0.04 for level 3. Small ICC values suggest that a two-level model would be appropriate; however, model misspecification results in less accurate fixed effect and standard error estimates, and inflation of lower-level variance estimates (Chen, 2012). Therefore, we specify the data using the more conceptually appropriate three-level model: instructors (level 1) are nested within departments (level 2) that are nested within institutions (level 3). Other studies (e.g., Porter and Umbach, 2001; Smart and Umbach, 2007; Yik et al., 2022) also use and advocate for these three-level models in similar contexts. Our previous work (Yik et al., 2022) describes the multilevel model used to evaluate the association of these same malleable factors with percent time lecturing.

TABLE 5 Summary of statistics to support reliability and unidimensionality of RBIS Adoption Scale.

Statistic	Sample	Chemistry	Mathematics	Physics
Coefficient of reproducibility (CR)	0.974	0.992	0.974	0.973
Minimal marginal reproducibility (MMR)	0.347	0.340	0.352	0.297
Percent improvement (PI)	0.627	0.652	0.622	0.676
Coefficient of scalability (CS)	0.960	0.988	0.960	0.965

Results

Multilevel models

We report the results of a national survey on the stages of RBIS adoption in introductory chemistry, mathematics, and physics in the United States. Data were collected and are modeled using three-level regression models based on the nested nature of the instructors (level 1) within departments (level 2) at institutions (level 3). 17 factors, comprised of 10 contextual, five personal, and two teacher thinking factors, are categorized using the TCSR model (Woodbury and Gess-Newsome, 2002; Gess-Newsome et al., 2003) in previous work (Yik et al., 2022). We report the results of two multilevel logistic regressions (i.e., RBIS Tryout and RBIS Adoption) using odd ratios (OR) which indicate the strength of the association between a predictor variable with the outcome variable (i.e., RBIS Tryout or Adoption) when all other predictor variables are accounted for in the model and held constant (Table 3).

Odds ratios are interpreted as the number of times higher when a variable is not zero when all other variables are held constant. For example, in the Tryout Model, academic discipline (i.e., chemistry, mathematics, physics) is evaluated using mathematics as the reference. When all other variables are held constant, the odds of RBIS tryout vs. RBIS awareness are not statistically different for instructors in chemistry departments ($OR = 0.92$, $p > 0.05$) than instructors in mathematics departments. However, the odds of RBIS tryout vs. RBIS awareness are 2.13 times higher for instructors in physics departments than for instructors in mathematics departments when all other variables are held constant. Odds ratios for the Adoption Model can be interpreted analogously where the odds ratio now represents the odds of RBIS adoption vs. RBIS tryout.

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TABLE 6 Distribution of stages of adoption.

Stage of adoption	Sample ($n=2,303$)	Chemistry ($n=768$)	Mathematics ($n=751$)	Physics ($n=784$)
Awareness	546 (23.7%)	177 (23.1%)	250 (33.3%)	119 (15.2%)
Tryout	533 (23.1%)	183 (23.8%)	180 (24.0%)	170 (21.7%)
Adoption	1,224 (53.2%)	408 (53.1%)	321 (42.7%)	495 (63.1%)

The Tryout Model and the Adoption Model both share some overlap in the statistically significant factors, but the models are also very different. Differences in the models further demonstrate (and corroborate the assumption) that two multilevel models better represent the data than a single multilevel ordered logistic regression model (i.e., proportional odds model) or multilevel multinomial logistic regression model. For the Tryout Model, statistically significant malleable factors include physics, class size, the interaction effect between class size and classroom setup, RBIS use as a student, teaching-related workshops, and satisfaction with student learning (see Table 3). For the Adoption Model, statistically significant malleable factors include physics, assessment of teaching performance, class size, classroom setup, RBIS use as a student, scholarship of teaching and learning, teaching-related new faculty experiences, growth mindset, and satisfaction with student learning (see Table 3).

Association of stages of RBIS adoption with percent lecturing

Our previous work (Yik et al., 2022) detailed the association of these malleable factors with percent lecturing. Stage of RBIS adoption and percent lecturing are two measures of active learning and comparison of these outcomes can provide further insight into the similarities and differences between these models. Table 7 presents the association of the stage of RBIS adoption with percent lecturing. A Kendall's tau-b correlation was calculated to determine the relationship between the stage of RBIS adoption and percent lecturing among the 2,266 respondents that provided useable data for all survey items used in this study including the RBIS Adoption Scale and percent lecturing. There is a medium-sized, negative association between stage of RBIS adoption and percent lecturing ($\tau_b = -0.335$, $p < 0.001$); increasing stage of RBIS adoption is associated with a decrease in percent lecturing.

Visualizations comparing the magnitude of the each of the instructor-level malleable factors between the Tryout Model and Percent Lecturing Model (Figure 1A) and the Adoption Model and Percent Lecturing Model (Figure 1B) are provided. In summary, nine malleable factors are statistically significantly associated with percent time lecturing: class size; classroom setup; the interaction effect between class size and classroom setup; decision making; RBIS use as a student; scholarship of teaching and learning; teaching-related workshops, new faculty experiences, and coursework; and growth mindset (Yik et al., 2022).

In comparing the Tryout Model and Percent Lecturing Model (Figure 1A), there are fewer instructor-level malleable factors associated with RBIS tryout than percent lecturing. Similarly, across the models, experience with RBIS as a student and participation in teaching-related workshops are associated with RBIS tryout and a decrease in percent lecturing. Inversely, larger class sizes are associated with RBIS tryout, but an increase in percent lecturing. Additionally, the interaction effect of larger class sizes in rooms that allow for group work and dissatisfaction with student learning are associated with RBIS tryout but are not significantly associated with percent lecturing.

In comparing the Adoption Model and Percent Lecturing Model (Figure 1B), there are nearly an equal number of instructor-level malleable factors associated with RBIS tryout as percent lecturing, however, there are differences. Classroom allowing for group work is the factor most strongly associated with RBIS adoption and decrease in percent lecturing. Other strongly associated factors in both models include engagement in SOTL/DBER, experience with RBIS as a student, participation in teaching-related workshops and new faculty experiences, and holding a growth mindset. Similarly, larger class sizes are associated with adoption of RBIS and increase in percent lecturing. However, satisfaction with student learning is associated with RBIS adoption, but is not significantly associated with percent lecturing. Two factors, shared decision making and previous teaching-focused coursework, are associated with a decrease in percent lecturing, but are not significantly associated with RBIS adoption.

Discussion

Multiple factors are associated with an increase in tryout and adoption of RBIS at the instructor level, when all other factors are held constant: assessment of teaching performance, class size, classroom setup, the interaction effect between class size and classroom setup, RBIS use as a student, participation in the scholarship of teaching and learning or discipline-based education research, teaching-related workshops, teaching-related new faculty experiences, holding a growth mindset, and satisfaction with student learning. Factors unique to either the Tryout Model or the Adoption Model allow for tangible recommendations for instructors in each group (i.e., those seeking to tryout an RBIS or those seeking to formally adopt an RBIS). Department-level factors (e.g., discipline and highest degree awarded) are unchangeable and thus lack formal implications in the context of this study; however, instructor-level factors can lead to tangible and practical implications for change efforts, and therefore, we will focus our discussion on these malleable instructor-level factors.

Importance of classroom spaces

Instructors continually note that teaching large classes in large fixed-seating classrooms (i.e., auditorium-style lecture

TABLE 7 Association of RBIS stages of adoption with percent lecturing.

Stage of adoption	Percent lecturing							
	Sample ($n = 2{,}266$)		Chemistry ($n = 761$)		Mathematics ($n = 732$)		Physics ($n = 773$)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Awareness	68.79	22.52	69.65	22.58	68.85	21.82	67.42	23.93
Tryout	65.70	21.66	68.09	20.74	62.20	21.03	66.77	22.92
Adoption	46.56	22.99	50.51	23.62	41.83	21.54	46.32	22.81

halls) make it difficult to promote student engagement and use RBIS (Henderson and Dancy, 2007; Hora, 2012; Lund and Stains, 2015; Sturtevant and Wheeler, 2019). Additionally, classrooms that can accommodate for group work, such as active learning classrooms or rooms with movable seats, desks, or tables, provide environments that are conducive to fostering student–student and student-instructor interactions (Beichner et al., 2007; Beichner, 2008; Cotner et al., 2013; Lund and Stains, 2015; Foote et al., 2016; Knaub et al., 2016). Our results indicate that instructors in the tryout and adoption stages are more likely to use RBIS as the class size becomes larger when compared to instructors in the awareness and tryout stages, respectively. However, instructors in the tryout stage are more likely than instructors in the awareness stage to implement RBIS regardless of the classroom space, but instructors in the adoption stage need (and potentially require or demand) classrooms that allow for group work. While class sizes have been reported to ease the facilitation of student engagement (Bressoud et al., 2015), our results indicate that instructors are less likely to use RBIS for smaller (< 30 students) class sizes.

Active learning, though, can occur in any classroom environment. Increasing odds of an instructor using RBIS when teaching larger courses suggest that uptake of RBIS is a means to make class sizes seem smaller by encouraging discussion and collaboration (Robert et al., 2016; Beane et al., 2020; Raker et al., 2021). For example, when large auditorium-style lecture halls are fitted with swivel chairs, students have been demonstrated to outperform their counterparts in a fixed-seat lecture hall (Ogilvie, 2008; Condon et al., 2016), which may be attributed to the room layout promoting discussion and collaboration. It has also been reported in the literature that various levels of student–student interactions can still be implemented with large class sizes in auditorium-style rooms (Lund et al., 2015).

Teaching large enrollment courses in classrooms that allow for group work is critical for instructors trying out RBIS. Classroom spaces designed to accommodate flexible teaching spaces can help aid in reducing barriers to implementing active learning (Ellis et al., 2016). These spaces may also help sustain the adoption of active learning practices due to the efforts it takes to learn about and support the implementation of these RBIS (Knaub et al., 2016). Instructors that have adopted RBIS may request to teach in such spaces because the space facilitates the use of active learning pedagogies, which can lead to further and sustained adoption (Foote et al., 2016).

Perceived value of assessment of teaching performance

Instructors' perceived value of how their department or institution values the assessment of teaching performance is influential in their pedagogies. Incentives guide instructors' professional decisions; for example, departments and institutions may require instructors to adopt RBIS in their teaching as a part of review, promotion, or tenure packages (Lund and Stains, 2015). Alternatively, if there are no structures in place to evaluate and reward instructors' teaching, then there can be little external incentive to adopt RBIS in their classes (Hativa, 1995; Walczyk et al., 2007; Brownell and Tanner, 2012; Elrod and Kezar, 2017; Shadle et al., 2017; Johnson et al., 2018). Our results suggest that greater the perceived influence of assessment performance on instructors' review, promotion, or tenure, the greater the odds of adoption of RBIS.

While instructors may be knowledgeable about and tryout RBIS, active learning strategies are most effective when instructors are committed to the pedagogy and are provided with ongoing support (Bressoud et al., 2015). For instructors to perceive emphasis on teaching, departmental (e.g., faculty and chairs) and institutional support (e.g., college, provost, dean) are needed for sustained change (Henderson and Dancy, 2007; Shadle et al., 2017; Carney et al., 2021; Dunnigan and Halcrow, 2021; Mingus and Koelling, 2021). Support of these endeavors can also come from other departments, centers for teaching and learning, and professional organizations (Mingus and Koelling, 2021). Departments and institutions can showcase value of teaching by rewarding instructors for their efforts in learning about, trying out, and adopting active learning strategies (Fairweather, 2008; Seymour et al., 2011; Wieman, 2015). Institutions can also support emphasis on adopting RBIS by providing travel support to external teaching-focused professional development programs and workshops (Reinholz and Apkarian, 2018; Carney et al., 2021), or small stipends or service credits to engage in institutional programs (Lotter et al., 2007; Foote et al., 2016; Herman et al., 2018; Reinholz and Apkarian, 2018).

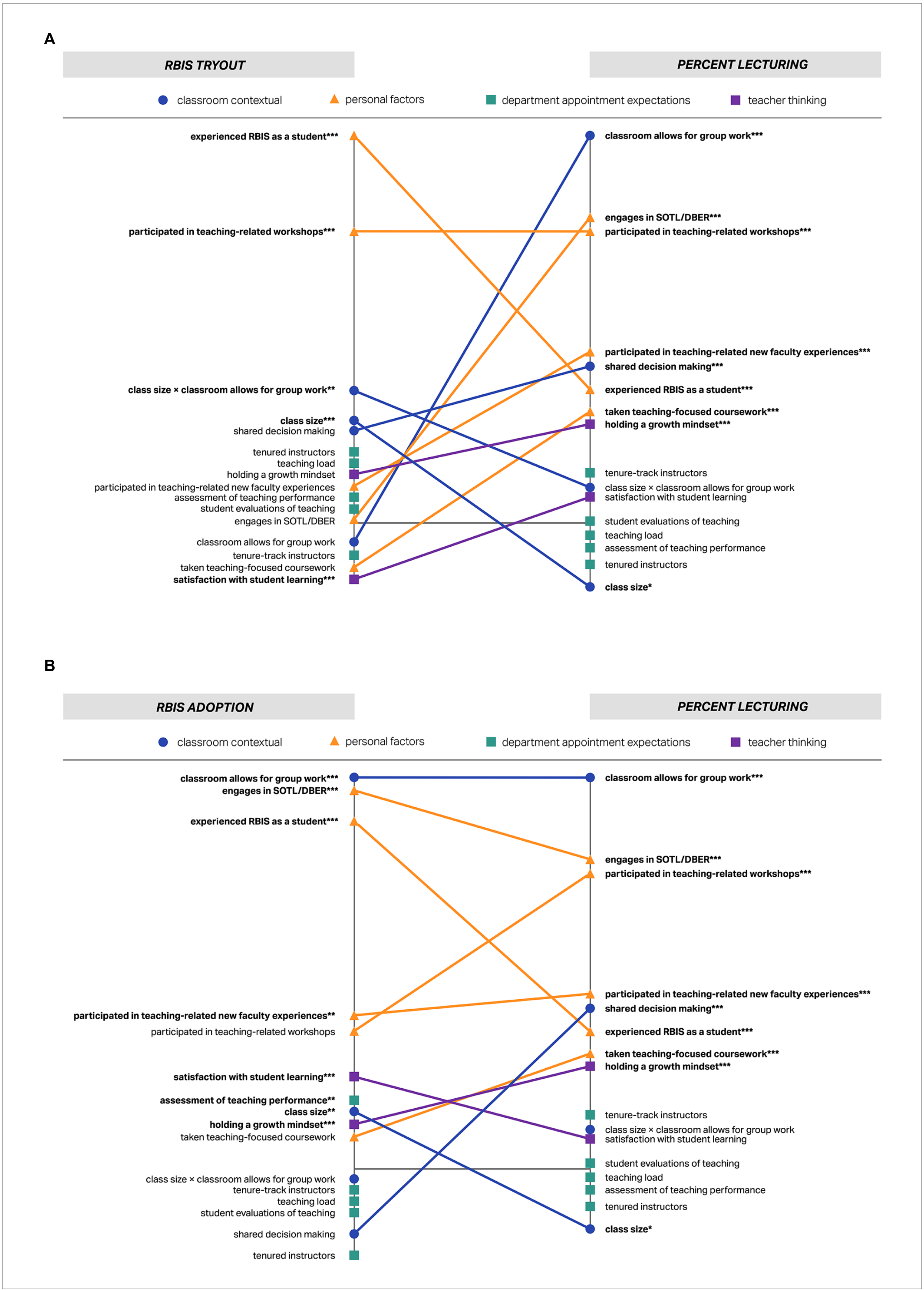
A
RBIS TRYOUT
PERCENT LECTURING
classroom contextual
personal factors
department appointment expectations
teacher thinking
experienced RBIS as a student***
participated in teaching-related workshops***
class size × classroom allows for group work**
class size***
shared decision making
tenured instructors
teaching load
holding a growth mindset
participated in teaching-related new faculty experiences
assessment of teaching performance
student evaluations of teaching
engages in SOTL/DBER
classroom allows for group work
tenure-track instructors
taken teaching-focused coursework
satisfaction with student learning***
classroom allows for group work***
engages in SOTL/DBER***
participated in teaching-related workshops***
participated in teaching-related new faculty experiences***
shared decision making***
experienced RBIS as a student***
taken teaching-focused coursework***
holding a growth mindset***
tenure-track instructors
class size × classroom allows for group work
satisfaction with student learning
student evaluations of teaching
teaching load
assessment of teaching performance
tenured instructors
class size*
B
RBIS ADOPTION
PERCENT LECTURING
classroom contextual
personal factors
department appointment expectations
teacher thinking
classroom allows for group work***
engages in SOTL/DBER***
experienced RBIS as a student***
participated in teaching-related new faculty experiences**
participated in teaching-related workshops
satisfaction with student learning***
assessment of teaching performance**
class size**
holding a growth mindset***
taken teaching-focused coursework
class size × classroom allows for group work
tenure-track instructors
teaching load
student evaluations of teaching
shared decision making
tenured instructors
classroom allows for group work***
engages in SOTL/DBER***
participated in teaching-related workshops***
participated in teaching-related new faculty experiences***
shared decision making***
experienced RBIS as a student***
taken teaching-focused coursework***
holding a growth mindset***
tenure-track instructors
class size × classroom allows for group work
satisfaction with student learning
student evaluations of teaching
teaching load
assessment of teaching performance
tenured instructors
class size*

FIGURE 1
Association of instructor-level malleable factors between **(A)** RBIS Tryout and Percent Lecturing Models and **(B)** RBIS Adoption and Percent Lecturing Models. *p<0.05, **p<0.01, ***p<0.001. Scaled magnitudes of odds ratios are shown on the left vertical axis (RBIS Tryout and Adoption) and scaled magnitudes of percentages are shown on the right vertical axis (Percent Lecturing). Additional levels for ordinal variables are not shown. The gray horizontal line indicates an odds ratio of one (RBIS Tryout and Adoption) and 0 % change (Percent Lecturing). Values above the horizontal line indicate of increased odds of **(A)** RBIS Tryout or **(B)** RBIS Adoption and decreased percent time lecturing; values below the horizontal line indicate of increased odds of **(A)** RBIS Awareness or **(B)** RBIS Tryout and increased percent time lecturing. Connecting lines indicate association between the same significant factor in both models, or between a factor that is significant in one model and not the other model.

Experience as a student in a course using research-based instructional strategies

The attitudes, beliefs, and intentions of instructors are partly a result of their own undergraduate and graduate education shaping the way that instructors currently enact pedagogies (Oleson and Hora, 2014; Lund and Stains, 2015; Fukawa-Connelly et al., 2016). Many instructors may have experienced more traditional, lecture-based instructional modalities as students, and thus, they may imitate these teaching styles in their own teaching practice (Adamson et al., 2003). However, instructors who experienced active learning a student have been reported to be more likely to implement active learning in their classes as an instructor (Lund and Stains, 2015; Yik et al., 2022). Our results support this idea; instructors who experienced RBIS as a student are more likely to tryout and adopt RBIS as an instructor. Experience with RBIS as a student is the highest influencing factor on RBIS tryout in our model; it is the among the highest for RBIS adoption, alongside class size and classroom effects.

The next generation of instructors, thus, will hopefully be greatly influenced by how we teach today. Our results point to the notion that “we teach the way we were taught” (Mazur, 2009). However, it is possible that instructors who use RBIS are more likely to recall the teaching strategies they experienced as a student, and those instructors who do not use RBIS are less likely to recall RBIS experiences when they were a student. Regardless, for lasting sustainable change in adopting active learning practices in introductory STEM courses, current instructors must adopt RBIS in their classes to influence the thinking of future instructors (i.e., current undergraduate and graduate students). Therefore, instructors must be incentivized to participate in teaching-related professional development and the scholarship of teaching and learning to assist in the adoption of RBIS.

Engagement in teaching-related professional development

Teaching-related workshops have many different forms from being more broad, such as how to manage a classroom and use the learning management system, to being more specific, such as on how to implement active learning strategies (e.g., Aebersold, 2019; Miller et al., 2021). Workshops have largely placed emphasis on develop–disseminate efforts to change individual instructor’s teaching practices (Beach et al., 2012; Borrego and Henderson, 2014), which stems from the belief that teaching is an individualistic effort (Tanner and Allen, 2006; Lane et al., 2019). Some studies suggest that these models for instructional change are generally ineffective (Henderson et al., 2011), and therefore, may not result in the desired widespread changes (Fairweather, 2008; Austin, 2011; Kezar, 2011; Froyd et al., 2017). However, our results demonstrate that participation in workshops aids instructors in trying out RBIS. Additionally, while participation in teaching-related new faculty experiences may not initially play a role in RBIS tryout, the effects of these experiences are prolonged by exhibiting a significant role in RBIS adoption.

Change can take place at many different levels, ranging from an individual instructor (Steinert et al., 2006), to departments [American Association of Colleges and Universities (AACU), 2014], and entire institutions (Elrod and Kezar, 2016). While change strategies may target a certain level, we recommend that change agents at all levels work together and support one another to achieve desired changes (American Association for the Advancement of Science (AAAS), 2019). Instructors should be active participants in their teaching roles and in learning about and adopting new teaching pedagogies (Fairweather, 2008; Smith et al., 2014; Quan et al., 2019). However, there can be a lack of incentives for instructors to participate in teaching-related professional development (Walczyk et al., 2007; Brownell and Tanner, 2012). External motivators to attend professional development events can greatly contribute to influencing instructors. Institutions and departments need to support, highly incentivize, and reward participation in these opportunities (Seymour et al., 2011; American Association for the Advancement of Science (AAAS), 2019; Bathgate et al., 2019b), and even stipends can act as a token of appreciation for instructors’ time and giving priority classroom preferences may sustain the adoption of RBIS (Soto and Marzocchi, 2021).

Continuing professional development is critical for the sustained implementation of active learning approaches (Speer and Wagner, 2009; Camburn, 2010; Quan et al., 2019; Pilgrim et al., 2021). Change in instructors’ beliefs and practices occur slowly (Derting et al., 2016). To facilitate successful change, interventions (e.g., teaching-related professional development) should last a semester or longer (Henderson et al., 2011). As time progresses, instructors may regress back to old teaching habits. It is necessary for instructors to continually engage with opportunities to learn about and demonstrate new teaching pedagogies (Brownell and Tanner, 2012). These opportunities should also be diverse across a continuum to assist instructors in their incremental growth in implementing active learning strategies (Soto and Marzocchi, 2021); our results show that instructors at the differing stages of adoption (i.e., awareness, tryout, and adoption) have different needs, and therefore, programs must be designed for instructors at various stages (Austin and Sorcinelli, 2013; Borda et al., 2020). Both teaching-related new faculty experiences and broader workshops are crucial for tryout and adoption of RBIS, and our results suggest that such programs should continue to be funded and operated.

Centers for teaching and learning serve as important resources for instructors to learn about, obtain advice on, and get help to properly implement RBIS. Additionally, these centers can support sustained adoption of RBIS through faculty learning communities (Cox, 2004; Pelletreau et al., 2018; Shadle et al., 2018; Dancy et al., 2019) and communities of practice (Henderson et al., 2017; Tomkin et al., 2019; Benabentos et al., 2021). One method is to incorporate faculty learning communities or communities of practice as a component of an extended (i.e., longer than one semester) new faculty experience (Beane-Katner, 2013). At institutions where centers for teaching and learning do not exist, instructor-organized communities may be effective at facilitating adoption of RBIS (Ma et al., 2019). Instructors can discuss teaching pedagogies through observation and feedback (Gormally et al., 2014; Smith et al., 2014) or successful adopters of RBIS may also engage with instructors trying out RBIS as form of peer-coaching (Desimone and Pak, 2017; Ma et al., 2018).

Participation in the scholarship of teaching

Engagement in the scholarship of teaching and learning (SOTL) has been reported to be related with improvements in course transformations (Henderson et al., 2011) and it is believed that practicing the closely related field of discipline-based education research (DBER) yields similar results (Henderson et al., 2012). Work has shown that instructors engaged in SOTL employed instructional practices that were more student-focused (Pelletreau et al., 2018; Dancy et al., 2019; Tomkin et al., 2019; Benabentos et al., 2021; Yik et al., 2022). In our study, participation in SOTL or DBER was associated with the RBIS adoption, but not RBIS tryout. Engagement in SOTL is an approach to develop reflective educators (Henderson et al., 2011). By agreeing to the statement, "I have evidence that my teaching has improved since I started using RBIS" in the RBIS Adoption Scale (Table 2), instructors are testifying to engaging in SOTL in their teaching. This leads to the ambiguity whether adoption of RBIS leads to SOTL or engaging in SOTL leads to the adoption of RBIS; regardless, instructors are employing active learning strategies and are becoming reflective educators.

Instructors participating in SOTL or DBER can help advance the adoption of RBIS of other instructors. Our previous study (Yik et al., 2022) detailed the association of shared decision on instructional methods with decreased time lecturing, and thus, increased time spent on active learning. Other work (Lane et al., 2020) suggested that instructors predominantly talk to other instructors with similar teaching approaches, i.e., RBIS users talk with other RBIS users. One approach to guide instructors to higher stages of RBIS adoption is through co-teaching (e.g., Henderson et al., 2009) or course coordination (e.g., Apkarian and Kirin, 2017), which can involve instructors at earlier or mid-stages of RBIS adoption (i.e., awareness and tryout) with SOTL, and also support sustained change and continuous course improvement over an extended period of time (Marbach-Ad et al., 2007, 2014; Reinholz and Apkarian, 2018; Mingus and Koelling, 2021).

Holding a growth mindset

Instructors' mindset has been shown to influence pedagogical decisions (Rattan et al., 2012; Aragón et al., 2018; Canning et al., 2019; Ferrare, 2019; Bathgate et al., 2019a; Richardson et al., 2020). Instructors holding a fixed mindset (i.e., student intelligence is fixed and cannot be changed; Dweck, 1999) adopt fewer active learning practices (Rattan et al., 2012; Aragón et al., 2018), and lecture more (Yik et al., 2022); correspondingly, instructors holding a growth mindset (i.e., student intelligence is malleable and can be improved with time and experience; Dweck, 1999) are more willing to consider (Johnson et al., 2018) and adopt more active learning practices (Aragón et al., 2018), and lecture less (Yik et al., 2022).

Our results show that mindset is not significantly associated with trying out RBIS but holding a growth mindset is significant in the adoption of RBIS; this finding mirrors previous findings that instructors' growth mindset beliefs is associated with a decrease in time spent lecturing (Yik et al., 2022). Fixed mindset beliefs are associated with greater odds of RBIS tryout than adoption, which may explain why instructors leave the innovation-decision process when using RBIS after an initial implementation (Henderson et al., 2012). Alternatively, espousing a growth mindset may increase instructors' persistence when adopting RBIS (Limeri et al., 2020).

Professional development workshops and experiences are possible avenues to promote instructors' growth mindset (Pilgrim et al., 2021; Yik et al., 2022). However, instructors have differences in their levels of motivation to participate in teaching-related professional development (Woodbury and Gess-Newsome, 2002; Bouwma-Gearhart, 2012; McCourt et al., 2017). Interventions to promote growth mindset for students have been demonstrated to be effective, generalizable, and replicable (Dweck and Leggett, 1988; Dweck, 1999; Yeager et al., 2016; Bettinger et al., 2018; Yeager et al., 2019), and psychosocial interventions can be leveraged to motivate instructors to participate in professional development that can emphasize growth mindset beliefs (see Limeri et al., 2020). This is particularly imperative because instructors' perceived mindsets have effects on students; students who perceive their instructors exhibiting growth mindsets are reported to have higher academic success, and positive motivational and psychological outcomes (Rattan et al., 2018; Fuesting et al., 2019; Lou and Noels, 2020; Muenks et al., 2020; LaCrosse et al., 2021), and this perception is strengthened with using active learning practices (Muenks et al., 2021). By holding a growth mindset, instructors are more likely to adopt RBIS and active learning, and resultingly, positively influence student outcomes.

(Dis)satisfaction with student learning

The misalignment of teaching practices with instructional goals and student outcomes can result in instructors' dissatisfaction with student learning or current instructional methods (Southerland et al., 2011a,b). The result of this disconnect between teacher thinking and practice can consequently lead to the adoption of new teaching strategies, such as RBIS (Feldman, 2000; Windschitl and Sahl, 2002; Gess-Newsome et al., 2003; Andrews and Lemons, 2015; Lund and Stains, 2015; Gibbons et al., 2018).

Our findings suggest that dissatisfaction with student learning is associated with the tryout of RBIS and the satisfaction with student learning is associated with the adoption of RBIS. Instructors' dissatisfaction with student learning may stem from dissatisfaction with the current pedagogy, which can include current RBIS use, and result in a change of teaching practices, and therefore, the trying out using (different) RBIS (Gess-Newsome et al., 2003). It can be postulated that once instructors are satisfied with their students' learning, it is due to the implemented pedagogies, and this satisfaction can lead to the sustained adoption of RBIS.

Change agents can leverage instructors' dissatisfaction or satisfaction with students learning in change strategies. For example, dissatisfied instructors are more likely to tryout RBIS. These instructors would be prime targets to engage in teaching-related workshops to learn about RBIS, be shown evidence of success using RBIS, and be provided training and resources to implement RBIS (Dormant, 2011). Additionally, satisfied instructors are more likely to adopt RBIS. These instructors can not only benefit from learning about and experimenting with new RBIS, but more importantly, having evidence that teaching has improved since using RBIS (Landrum et al., 2017). Change agents can identify these instructors as participants to engage in the scholarship of teaching and learning; by engaging in SOTL, instructors will have evidence that shows supported student learning, and thus, instructor satisfaction.

Association of malleable factors with RBIS tryout, adoption, and percent lecturing

The malleable factors associated with RBIS tryout and RBIS adoption are similar, but also different, to the malleable factors associated with percent lecturing. In all three regression models, only one factor has an association with higher odds of RBIS tryout and adoption and a decrease percent lecturing: experience in a course using RBIS as a student. Therefore, it is vital we ensure that current instructors adopt RBIS such that our current students (i.e., our future instructors) are more likely to implement and adopt RBIS and active learning strategies in the future.

Tryout and adoption of RBIS and percent lecturing are different measures of active learning. To such an end, the malleable factors used to consider change strategies differ depending on the desire to influence RBIS tryout, RBIS adoption, or percent lecturing. Regardless of the exact malleable factors chosen to inform change, *any* of the factors significantly associated with *any* of the three outcomes (i.e., RBIS tryout, RBIS adoption, and percent lecturing) have greater odds of increasing the uptake of active learning strategies.

Limitations

Findings from this study are constrained by three noteworthy limitations. First, this study is limited to the disciplines of chemistry, mathematics, and physics, and is therefore limited in disciplinary scope; additionally, survey respondents were comprised of instructors from the introductory courses of these disciplines, and is therefore limited in course scope. Other survey-based studies illustrate differences between lower-and upper-level STEM courses (Benabentos et al., 2021) and observation-based studies report instructors are more likely to implement RBIS in introductory courses than in more advanced courses (Lund et al., 2015). Inclusion of additional STEM disciplines and courses would be in productive space for future studies.

Second, higher education is a complex system. The TCSR framework focuses on instructor beliefs and instructors as the primary change agents at an institution (Gess-Newsome et al., 2003). In our conceptualization of the TCSR framework, we situate barriers and motivations for instructional change into contextual factors, personal factors, and teacher thinking factors; however, it would be unfeasible to model every single possible factor in a regression model. For example, our study does not consider student-level factors. Some students are reported to find active learning classes to be disjointed with an overall feeling of frustration and confusion and many studies note student resistance as a barrier to implement active learning strategies (Deslauriers et al., 2019; Owens et al., 2020).

Lastly, plausible reliability threats may be due to the self-reported nature of our survey items. While we have provided evidence for the reliability of the instrument (i.e., RBIS Adoption Scale) used to obtain the outcome measure (i.e., stage of RBIS adoption), there may be reliability threats to survey items that correspond to respondents' contextual, personal, and teacher thinking factors. Nonetheless, studies have demonstrated evidence to suggest that self-reported data regarding teaching practices align well with observational data (Durham et al., 2018; Gibbons et al., 2018), and data from observation-based studies would complement data from survey studies.

Conclusion

Findings from this study are constrained by three noteworthy limitations. First, this study is limited to the disciplines of chemistry, mathematics, and physics, and is therefore limited in disciplinary scope; additionally.

We advocate for the sustained adoption of research-based instructional strategies to promote use of active learning in introductory STEM courses. There are boundless paths instructors and change agents can take to that lead to a student-centered classroom which incorporates active learning strategies, and instructors should adopt RBIS that best fits the characteristics of their unique classroom contexts (Budd et al., 2013; Beane et al., 2020). In this journey on instructional change, instructors must be first aware of RBIS, tryout these strategies, and then adopt the pedagogies. The RBIS Adoption Scale is a quick, efficient, and reliable instrument to gage instructors' stage of RBIS adoption; using this information, change agents can help facilitate instructors' course transformation journeys. We offer recommendations for change agents to provide directed opportunities for instructors.

Recommendations for targeting instructors aware of RBIS and are working toward trying out RBIS:

- Identify instructors that are dissatisfied with their students' learning
- Design workshops that provide training and resources to implement RBIS, and highlight the success stories and research-based data of those RBIS
- Encourage instructors that teach large class sizes to seek out classrooms that allow for group work and introduce RBIS that large class sizes appear smaller

Recommendations for targeting instructors trying out RBIS and are working toward adopting RBIS:

- Demonstrate the need to assess student learning with evidence when RBIS are implemented
- Engage instructors in SOTL so that instructors have the knowledge and resources to obtain evidence of enhanced student learning
- Encourage instructors to teach in classrooms that allow for group work, irrespective of class sizes
- Help foster growth mindset beliefs through interventions or other professional development programs

Recommendations for institutional leaders and policy makers:

- Value and reward teaching and instructors' efforts in instructional change
- Build classroom spaces that allow for group work
- Encourage and incentivize the participation in teaching-related new faculty experiences and workshops
- Showcase benefits of RBIS and promote the uptake of RBIS use

The results from our national survey of introductory chemistry, mathematics, and physics instructors that evaluates the association of malleable factors with the adoption of active learning inform these recommendations for change agents, institutional leaders, and policy makers. Our goal is for these recommendations to inform instructor-focused change initiatives that result in meaningful and sustainable change around teaching practices.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Western Michigan University. The patients/participants provided their written informed consent to participate in this study.

Author contributions

CH, MD, EJ, JR, and MS obtained financial support and conceived of the study. CH, MD, EJ, JR, MS, and NA designed the survey. NA cleaned and compiled the data. BY, JR, NA, and MS analyzed the data. BY carried out the formal analysis of the data and wrote the paper. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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