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Prior experiences as students and instructors play a critical role in instructors' decision to adopt evidence-based instructional practices

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Abstract

Background There has been a growing interest in characterizing factors influencing teaching decisions of science, technology, engineering, and mathematics (STEM) instructors in order to address the slow uptake of evidence-based instructional practices (EBIPs). This growing body of research has identified contextual factors (e.g., classroom layout, departmental norms) as primary influencers of STEM instructors' decision to implement EBIPs in their courses. However, models of influences on instructional practices indicate that context is only one type of factor to consider. Other factors fall at the individual level such as instructors' past teaching experience and their views on learning. Few studies have been able to explore in depth the role of these individual factors on the adoption of EBIPs since it is challenging to control for contextual features when studying current instructors. Moreover, most studies exploring adoption of EBIPs do not take into account the distinctive features of each EBIP and the influence these features may have on the decision to adopt the EBIP. Rather, studies typically explore barriers and drivers to the implementation of EBIPs in general. In this study, we address these gaps in the literature by conducting an in-depth exploration of individual factors and EBIPs' features that influence nine future STEM instructors' decisions to incorporate a selected set of EBIPs in their teaching.

Results We had hypothesized that the future instructors would have different reasoning to support their decisions to adopt or not Peer Instruction and the 5E Model as the two EBIPs have distinctive features. However, our results demonstrate that instructors based their decisions on similar factors. In particular, we found that the main drivers of their decisions were (1) the compatibility of the EBIP with their past experiences as students and instructors as well as teaching values and (2) experiences provided in the pedagogical course they were enrolled in.

Conclusions This study demonstrates that when considering the adoption of EBIPs, there is a need to look beyond solely contextual influences on instructor's decisions to innovate in their courses and explore individual factors. Moreover, professional development programs should leverage their participants past experiences as students and instructors and provide an opportunity for instructors to experience new EBIPs as learners and instructors.

Keywords Instructor thinking, Case study, Evidence-based instructional practices, Teaching practices, Higher education, Professional development

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Introduction

Extensive research on students' experiences and outcomes in science, technology, engineering, and mathematics (STEM) courses has fueled instructional reforms for decades. In particular, the literature has demonstrated that the instruction provided in introductory STEM courses is one of the main reasons students leave

STEM fields (National Research Council, 2012; Seymour & Hunter, 2019). Moreover, the discipline-based education research literature has shown that students leave STEM courses with an inadequate understanding of core concepts (e.g., Brownell et al., 2014; Cooper et al., 2015a, 2015b; Luxford & Bretz, 2013; Steenkamp et al., 2021; Talanquer, 2016) and limited opportunities to learn scientific practices (e.g., Cooper, 2015; Killpack & Popolizio, 2023; Lewandowski & Finkelstein, 2015; Stowe & Cooper, 2017). Importantly, the instructional approaches employed in STEM courses are especially detrimental to minoritized students (e.g., Freeman et al., 2014; Haak et al., 2011). Discipline-based education researchers have been working towards addressing these problematic outcomes by developing, evaluating, and subsequently promoting new instructional strategies and resources, known collectively as Evidence-Based Instructional Practices (EBIPs). EBIPs are described as "curricular interventions, programs, and instructional techniques with methodologically rigorous research bases supporting their effectiveness" (Missett & Foster, 2015, p. 97) and are a subset of active learning practices that have been shown to improve student learning outcomes (Freeman et al., 2014; Rahman & Lewis, 2020; Theobald et al., 2020).

While extensive national and institutional efforts have been dedicated to promoting the adoption of EBIPs over the previous decades, adoption has been slow (American Association for the Advancement of Science, 2019; Stains et al., 2018). The slow uptake has prompted explorations of STEM instructors' knowledge of EBIPs and the factors influencing their decision to integrate EBIPs into their courses. Numerous survey-based studies have reported a high level of awareness of EBIPs among STEM instructors but a low level of self-reported use (Borrego et al., 2010; Chasteen & Chattergoon, 2020; Dancy et al., 2016; Gibbons et al., 2018; Henderson et al., 2012; Lund & Stains, 2015; Macdonald et al., 2018; Raker et al., 2021; Yik et al., 2022a). For example, a national study of 2303 introductory chemistry, physics, and mathematics instructors showed that while nearly all respondents were aware of EBIPs, only just over half were consistently using one or more EBIPs in their courses (Yik et al., 2022a). Consequently, the lack of uptake is not due to a lack of knowledge. The education research community has thus been interested in identifying factors that can explain this gap.

Discipline-based education researchers have focused these investigations on two domains of influence: *individual* factors, which are unique to each instructor (e.g., teaching experience, participation in professional development programs, or their thinking about teaching and learning) and *contextual* factors, which relate to the structure and culture of the environment in which instructors teach (e.g., class size, departmental culture, or institutional promotion and tenure policies). Several studies have used these two domains to frame their investigation into factors contributing to STEM instructors' instructional thinking and practices (Emery et al., 2021; Henderson & Dancy, 2007; Henderson et al., 2011; Popova et al., 2021; Sansom et al., 2023; Yik et al., 2022a, 2022b). Overall, this body of work has identified contextual factors as prevalent barriers to the adoption of EBIPs. These factors include lack of departmental norms for teaching using EBIPs (e.g., Dancy & Henderson, 2008), little incentive for instructional innovation because faculty reward structure favors research (Michael, 2007), inadequate classroom infrastructure (e.g., Sturtevant & Wheeler, 2019), student resistance (e.g., Shadle et al., 2017), expectations for content coverage (e.g., Henderson & Dancy, 2007), and time constraints (e.g., Turpen et al., 2016). While contextual factors clearly play a critical role in the instructional decision-making process, studies have indicated that individual factors should not be ignored. For example, Yik et al. (2022b) found that having experienced EBIPs as a student was associated with a decrease in the amount of time an instructor lectures. Similarly, Turpen et al. (2016) observed that physics instructors' choices regarding the adoption of Peer Instruction (PI; Mazur, 1997), a specific EBIP, were strongly influenced by their personal encounters with PI either as instructors or learners. It is thus important to further characterize the role of individual factors in the instructional decision-making process. However, it is challenging to isolate and characterize the role of individual factors when instructors are immersed in their academic unit and subject to a variety of contextual factors. In this study, we focus on a population of instructors for which the typical academic context (e.g., promotion and tenure policies, departmental norms around teaching, class size, external expectations for content coverage, time constraints) was not immediately pertinent (i.e., STEM graduate students enrolled in a pedagogical course) and use a case study approach to explore individual factors that influence these future STEM instructors' decisions to integrate EBIPs into their teaching.

Prior research on the factors influencing the adoption of innovative instructional practices has generally focused on either EBIPs as a collective or more broadly on active learning, rather than on specific instructional practices. For example, in the aforementioned study by Yik et al. (2022b), the researchers used a broad view of EBIPs by measuring the percent of time spent lecturing as a proMS for the percent of time *not* using active learning/EBIPs. It is necessary to recognize that EBIPs are not one-size-fits-all and evidence suggests that instructors may perceive individual EBIPs differently from a broad collection of EBIPs (Genné-Bacon et al., 2020). Each EBIP has its own design and purpose, and thus instructors will likely need to weigh different features, such as EBIP complexity or time investment, when deciding to implement these practices (e.g., Chase et al., 2013; Henderson & Dancy, 2009). It is therefore essential to characterize these nuances to obtain a more refined understanding of the factors that influence instructors' decisions about specific EBIP adoption. In this study, we investigate factors that influence future instructors' decision to use two specific EBIPs: Peer Instruction (Mazur, 1997) and the 5E Model (Bybee et al., 2006).

In summary, this study aims to characterize individual factors as well as features of specific EBIPs that influence an instructor's decision to integrate EBIPs in their teaching. The research question guiding this study was: *What factors influence future STEM instructors' choice to integrate a specific evidence-based instructional practice into their teaching?*

Conceptual framework

We leveraged two frameworks from the literature to develop the conceptual framework guiding this study: the Teacher-Centered Systemic Reform Model (TCSR, Gess-Newsome et al., 2003) and the Innovation-Decision Process Model (Rogers, 2003).

Teacher-centered systemic reform model

An exhaustive review of the secondary education literature by Woodbury and Gess-Newsome led to the development of the Teacher-Centered Systemic Reform (TCSR) model which describes the factors contributing to instructional practices (Gess-Newsome et al., 2003; Woodbury & Gess-Newsome, 2002). Specifically, this model outlines three broad factors that influence an instructor's practice: personal factors, teacher thinking factors, and contextual factors. Personal factors include the instructor's demographic profile, the types and years of teaching experience, and the nature and extent of previous and continued training in teaching. Teacher thinking refers to the knowledge and beliefs instructors have about teaching and learning (e.g., about teachers, learners, and subject matter). Contextual factors include the structural and cultural environments. These range from a broad community context (e.g., professional organizations or textbooks), to those of a particular institution (e.g., institution type), the department (e.g., cultural norms of interaction within a department), and the classroom context (e.g., class size or layout). The TCSR model depicts these three broad factors as interconnected in a system that informs one's instructional practice (Fig. 1).

Innovation-Decision Process Model

The Innovation-Decision Process Model (articulated as part of Roger's Diffusion of Innovations Theory) was used as the second model in our conceptual framework to provide a more granular view of the factors influencing the decision to adopt a specific EBIP (Rogers, 2003). This model has previously been found fruitful by discipline-based education researchers to explain the adoption of instructional innovations such as EBIPs (e.g., Andrews & Lemons, 2015; Gardner et al., 2021; Henderson, 2005; Lund & Stains, 2015; McConnell et al., 2020). This model outlines a series of five stages (Fig. 2), whereby an individual begins by becoming aware of the innovation and gaining *knowledge* about its function. Following this, an individual forms an attitude towards the innovation which is described as the *persuasion* stage. In the next phase, the individual makes a *decision* to adopt or reject the use of the innovation. If the decision is to adopt, the individual then tests the innovation (*implementation*) to establish its usefulness. Finally, the individual reflects on the implementation stage and looks for *confirmation* as to whether they will continue or discontinue its use.

Although the Innovation-Decision Process Model is not strictly a linear process, it is often depicted as one. Rogers (2003) noted that the order of the first three stages is not a set path, as an instructor can be persuaded before they have knowledge of the EBIP's function. Therefore,

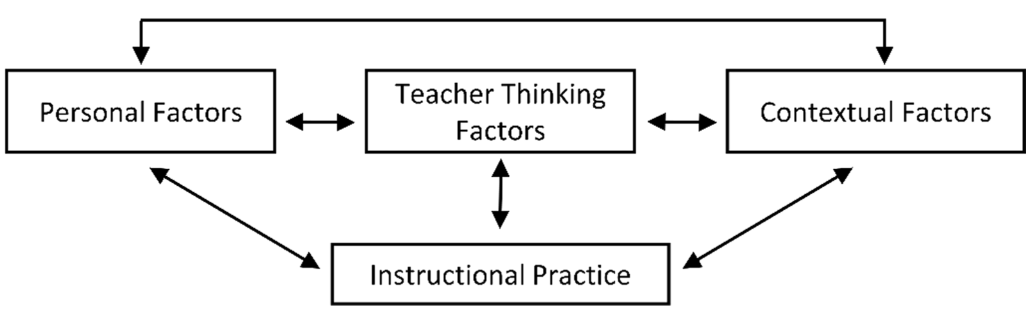

Fig. 1 Teacher-centered systemic reform model adapted from Gess-Newsome et al., (2003)

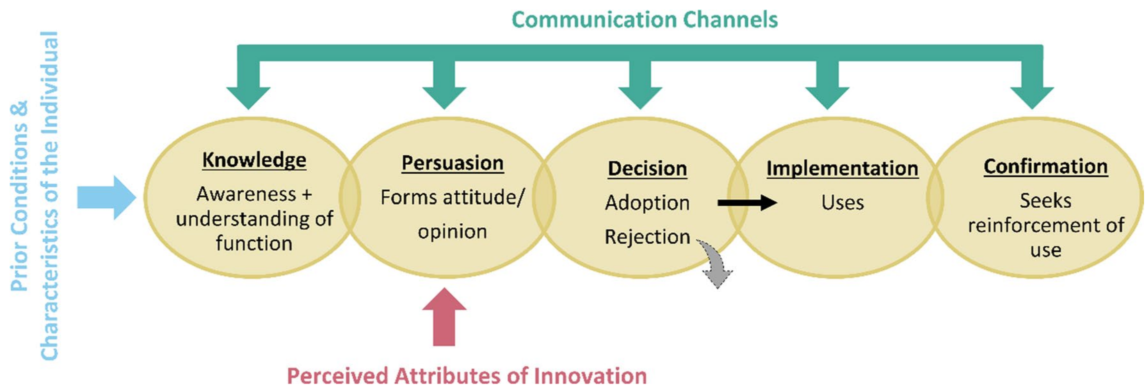

Fig. 2 Innovation-decision process model adapted from diffusion of innovations (Rogers, 2003)

we chose to visualize the model as overlapping circles to illustrate that there is not only one continuous path forward, but rather an instructor may move back and forth between the different stages (Fig. 2). It is important to note that this five-stage decision process does not occur in a vacuum; it includes several factors that influence the rate of adoption of the innovation.

Rogers (2003) identifies four factors impacting the rate of adoption of an innovation (see arrows in Fig. 2): (1) prior conditions that exist before entering into the process (e.g., previous instructional practice, experiences as student); (2) the characteristics of the individual making the decision (e.g., personal beliefs about teaching); (3) the perceived attributes of the innovation (Table 1); and (4) the communication channels which are the means of message exchange from a source to a receiver (e.g., professional development workshops). We chose to combine the first two factors (i.e., prior conditions and characteristics of the individual) into one input arrow in our model as these both contribute to the beginning of the decision process.

The Innovation-Decision Process Model has been used to explore instructors' interactions with and adoption of student-centered teaching and EBIPs. Studies have primarily focused on identifying the stage at which instructors are (e.g., *knowledge* and *implementation*), rather than tracing their movement through the stages (Dancy et al., 2016; Henderson et al., 2012). Accordingly, we have limited knowledge as to how instructors progress in their decision-making. In particular, it is unclear how instructors move from the *knowledge* stage to the *decision* stage—a critical steppingstone on the way to adoption. Moreover, only a few studies have investigated the factors influencing the decision process as it relates to the adoption of specific EBIPs (Andrews & Lemons, 2015; Foote et al., 2014; Genné-Bacon et al., 2020; Montfort et al., 2012; Turpen et al., 2016). One study investigated the perceived affordances and constraints that 35 physics instructors experience regarding their implementation of PI (Turpen et al., 2016). The researchers found that both users and non-users of PI cited evidence from personal experiences as a prevalent reason for their decision to use or not use PI. Over half of the participants supported the use of PI because of their own positive past experiences with the practice (e.g., their own past use as an instructor, observation of another instructor using PI, or their experience with PI as a learner). On the other hand, a third of the participants reported negative prior experiences with the practice, which contributed to their decision not to use PI. Another study interviewed 17 biology instructors to characterize the process of adopting and sustaining the use of case study teaching (Andrews & Lemons, 2015).

Table 1 Perceived attributes of an innovation as defined in Rogers (2003)

Perceived attributes	Definition
Relative advantage	"The degree to which an innovation is perceived as being better than the idea it supersedes" (p. 229)
Compatibility	"The degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters" (p. 240)
Complexity	"The degree to which an innovation is perceived as relatively difficult to understand and use" (p. 257)
Trialability	"The degree to which an innovation may be experimented with on a limited basis" (p. 258)
Observability	"The degree to which the results of an innovation are visible to others" (p. 258)

Their findings indicated that the instructors prioritized personal experiences over empirical evidence in their instructional decisions.

Genné-Bacon et al. (2020) study uniquely focused on the perceived attributes of the innovation Course-based Undergraduate Research Experiences (CURE; Dolan, 2016). They sought to compare instructors' perceptions of CURE courses in general and a specific CURE called Prevalence of Antibiotic Resistance in the Environment (PARE). Results showed that instructors believed both CUREs and PARE had relative advantages over traditional methods. For CURE, instructors reported compatibility of CURE courses, broadly speaking, with their past experiences as well as their values and beliefs, but viewed CURE courses as complex and cited multiple barriers to their implementation. For PARE, the most prominent compatibility factor was alignment with the instructor's context and resources and instructors cited fewer barriers to implementation. This study clearly demonstrates how particular attributes of the innovation contribute to instructors' decisions to adopt/reject individual EBIPs and showcases the variability in instructor thinking when comparing a broad collection of EBIPs with a specific EBIP.

The study herein leverages these two frameworks to explore future STEM instructors' thinking about their decisions to use two particular EBIPs in their teaching. Our conceptual framework (Fig. 3) is situated within the TCSR model but leverages the Innovation-Decision Process Model to clarify an implicit piece of the TCSR: the decision point that instructors pass through when considering the integration of an EBIP in their instructional practice. We chose a purposeful sample of future STEM instructors as they were not immediately immersed in a typical postsecondary teaching context. Indeed, the study participants come from a graduate-level pedagogical course in which students were asked to design and implement a mock teaching lesson within their ideal context (i.e., they chose their ideal class size and layout and had no content coverage constraint). We hypothesized that the contextual factors for adoption of EBIPS by STEM instructors that have been extensively reported in the literature (e.g., pressures due to promotion and tenure policies or departmental teaching norms, constraints due to expectations of content coverage by peers or accrediting agency) would play a minimal role in the EBIP adoption decision process of these future STEM instructors, and that individual factors (i.e., personal and teacher thinking) would be more prominent and detectable in these participants compared to currently employed instructors. In Fig. 3, we thus relabeled and greyed out the Contextual Factors box from Fig. 1 to highlight that these future instructors are not making choices within the typical context of a STEM postsecondary instructors which has been the focus of the literature.

Methods

A multiple explanatory case study methodology was used for this study as it aims to explain the cause of an event or phenomenon of interest through in-depth explorations (Yin, 2009). This approach was appropriate for our research question which sought to explain the underlying factors influencing future STEM instructors' decisions to adopt EBIPs. This study was carried out as approved by the Institutional Review Board where the study took place (IRB-SBS #4200). Participants were recruited from a graduate-level course entitled "Teaching for the Science Class" (herein referred to as: "the course") taught by author MS. A variety of data sources were collected including surveys, interviews, observations, and course

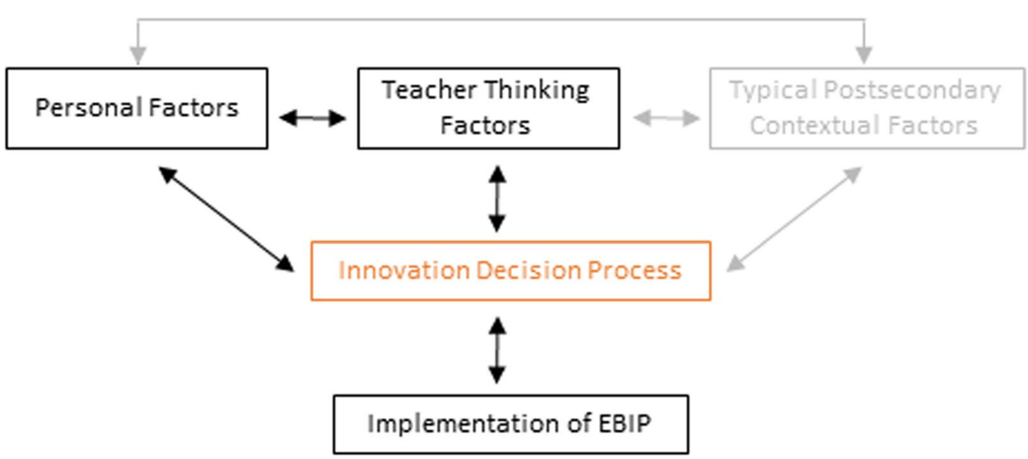

Fig. 3 Conceptual framework used in this study

artifacts. Study participants were compensated with $40 for their time upon completion of the post-survey and post-interview.

Study context

The course was open to both graduate and upper-level undergraduate students at a large, public, research-intensive institution in the Mid-Atlantic region of the United States. The course met once per week for two and a half hours throughout the spring semester. The content goals of the course were to introduce various EBIPs and associated learning theories. A key part of the EBIP introduction was having students (i.e., participants) experience EBIPs from the perspective of both a student and an instructor. As part of the course, participants also developed a teaching philosophy statement and were provided with opportunities to develop, implement, and receive feedback on a mock teaching lesson that they taught. More details about the course are provided in the Supplementary Information.

Participants

Purposeful sampling is a method of data collection in which the investigator intentionally selects their participants based on some characteristic(s) of interest to gain greater understanding. It thus leads to the selection of participants from which the most can be learned (Merriam & Tisdell, 2016). The participants from the course described above provided the criteria and environment for the unique population we sought to study, i.e., future postsecondary STEM instructors that were not yet embedded in a typical academic context that could constrain their decision-making processes. We thus refer to participants as "future instructors" in this study. Participants were recruited from the Spring 2021 and 2022 iterations of the course. It is important to note due to the COVID-19 pandemic, the Spring 2021 course was held as a synchronous online course, whereas the Spring 2022 course was an in-person course. A total of 11 students from a variety of STEM disciplines (i.e., astronomy, biology, chemistry, chemical engineering, and microbiology) were enrolled in the course over the two semesters. Ten students consented to participate in the study. One participant was excluded from analysis due to their robust prior teaching experience beyond that of a typical teaching assistant; rather than making new decisions for the design of their mock lesson plan, this participant heavily drew upon their previous work. Thus, we concluded that this student was not representative of our intended population and their data were not included in the analysis. To protect participants' identities, identifying information was removed from the data, and each participant was assigned a pseudonym and they/them pronouns. Participants' teaching experiences and pedagogical training prior to their enrollment in the course are provided in Table 2.

Ethical considerations

Author ARK attended each class strictly as an observer, had no administrative role in grading to avoid any potential conflict of interest, and was the primary data analyst for this study. Author MS was the instructor of record for the course; however, she did not serve in a data analyst role until after course completion and grade submission. Authors ELA and LS were not involved in the course.

Table 2 Participants' prior teaching experience and involvement in teaching professional development

Cohort	Participant pseudonym	Teaching experience	Prior participation in teaching professional development
1	Charlie	UTA—4 semesters	Enrolled in one credit course to prepare TAs as an undergraduate student
	Dakota	GTA—5 semesters	None
	Finley	UTA—7 semesters GTA—2 semesters	None
	Lincoln	UTA—2 semesters	None
	Morgan	UTA—1 semester GTA—2 semesters	Attended workshops as part of their participation in a graduate program at their institution that sought to prepare future instructors
2	Kennedy	UTA—2 semesters*	None
	Quinn	UTA—4 semesters	None
	Skyler	UTA—7 semesters GTA—2 semesters	Attended a brief seminar before each semester they taught as a UTA and participated in a workshop prior to their first assignment as a laboratory GTA
	Taylor	GTA—1 semester*	Attended workshops from their institutional teaching and learning center on preparing graduate students for the first day of class, providing feedback, and being a learning facilitator

Undergraduate teaching assistant is abbreviated as UTA and graduate teaching assistant is abbreviated as GTA

*Denotes concurrent teaching assignment held at the time of enrollment in the course

Data collection

This study was designed to triangulate across different forms of data, including surveys, course artifacts, observations, and interviews, and was collected over two semesters (Spring 2021 and 2022; see Additional file 1: Figure S1 for timeline of data collection throughout the semester). This collection of data aimed to identify factors associated to the adoption of EBIPs presented in the TCSR and Roger's Innovation-Decision Process Model. Figure 4 provides the factors measured in this study and their alignment with both frameworks.

A pre-class survey (see Supplementary Materials) was administered near the start of the course to gather a baseline of participants' prior knowledge and experience with the EBIPs introduced in the course, their teaching experience, and their participation in teaching-related professional development. The survey also probed the participants about their teaching values via a set of metaphors, their motivation and confidence in implementing EBIPs as well as their thoughts on the effectiveness, advantages, and disadvantages of EBIPs.

Course artifacts were collected to capture participants' perceptions of the EBIPs, understand their teaching values, and identify their EBIP adoption decisions. These artifacts included (1) a paper collected at the beginning of the semester describing the course and the mock lesson they were planning on developing; (2) drafts and final version of the mock lesson plan and reflection; (3) a PowerPoint of students' mock lessons; (4) teaching philosophy statement drafts and a reflection; (5) Just-in-Time-Teaching assignments; and (6) Teaching Toolcards. The Teaching Toolcard was developed by authors ARK and MS. It was designed to resemble a recipe card that provided a template and prompts for participants to summarize and reflect on an individual EBIP (see Additional file 1). One section of this document explicitly asked participants about their perceived attributes of the EBIP (see Table 1); specifically, this included the perceived relative advantage, compatibility, and complexity of the EBIP. Participants completed a Teaching Tool card for each of five EBIPs that were introduced in the course, including PI and the 5E Model.

A post-course survey was distributed at the end of the course to understand the contribution of different factors that informed participants' decisions about their EBIP implementation in their mock lesson (see Additional file 1).

After the course was completed, semi-structured interviews were conducted with each participant in order to unpack and enrich the data gathered from the course artifacts and surveys (see Supplementary Materials). Ultimately these interviews focused on factors that impacted participants' decision as to whether or not to incorporate two specific EBIPs in their mock lesson. Interviews

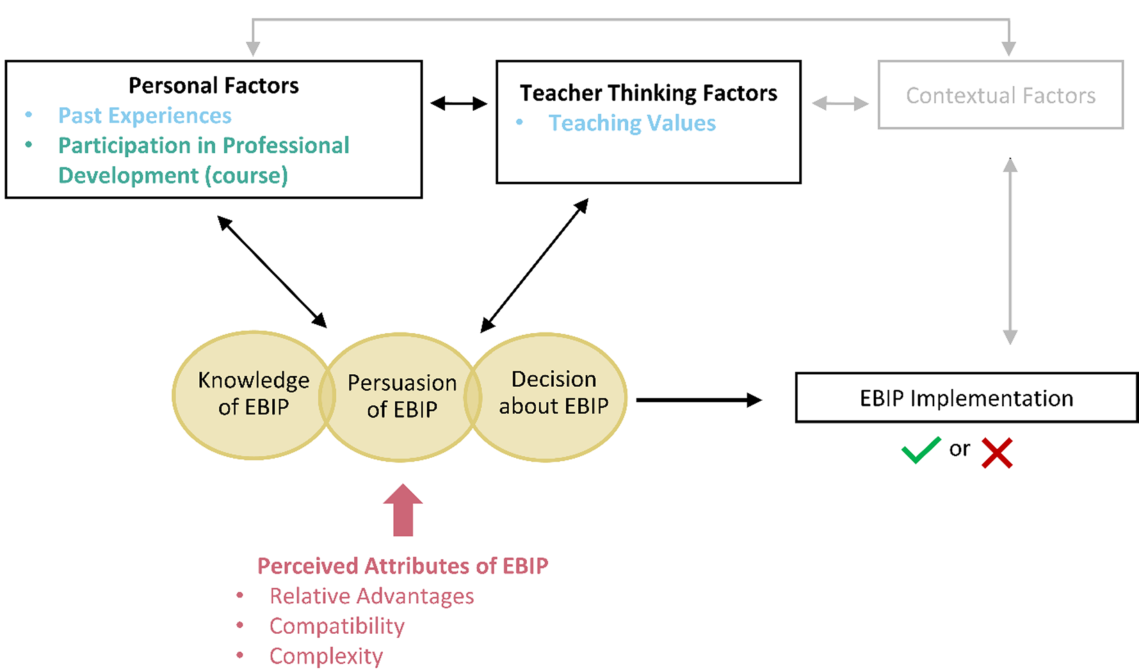

Fig. 4 Alignment of factors measured in this study with the factors from the TCSR and Roger's Innovation-Decision Process Model. The **Blue text** represents factors related to the "Prior Conditions & Characteristics of the Individual" factor from Roger's model. The **Green text** represents factors related to the "Communication Channels" factor from Roger's model. The **Pink text** represents the "Perceived Attributes of the Innovation" factors from Roger's model

also served as a member-checking opportunity for the researcher to confirm participants' experience with the EBIPs and the themes identified in their teaching philosophy. Interviews were recorded, transcribed using an online transcription service (Temi.com), and checked for accuracy by author ARK.

We triangulated across multiple data sources to characterize these future instructors' teaching values. First, participants wrote a teaching philosophy statement articulating their values, goals, and conceptions of teaching and learning as part of the course where this study was situated. Crafting of the statement included multiple iterations, reflection, and feedback from peers and the course instructor. Second, in the pre- and post-surveys, participants were provided with a list of six metaphors describing teaching: teaching is guiding, teaching is nurturing, teaching is molding, teaching is transmitting, and teaching is providing tools (see Additional file 1; Alger, 2009). Participants were asked which, if any, aligned with their views of teaching and learning. The provided metaphors helped participants to further describe their preferred instructional role in the classroom. Lastly, in the post-interview, participants were asked to elaborate on their teaching philosophy statement, metaphor selection, the alignment between the teaching philosophy statement and metaphor selection, and the alignment between the teaching philosophy statement and executed mock lesson plan.

As part of data collection process, author ARK was immersed in the experiences of the participants as she observed all course sessions for both iterations. These observations served to inform the post-interviews and were not used for collecting data for analysis except for select class periods that captured future instructors' implementation of EBIPs, which were recorded. These recordings were revisited, if needed, to better understand participants' thinking and use of the specific EBIPs.

Adjustments to data collection instruments were made between Cohort 1 and 2: revisions of survey items for clarity, the addition of a pre-interview for the purpose of collecting richer prior experience with the EBIPs investigated (see Additional file 1), and the addition of prompts to existing course assignments to elicit reflections on the use of EBIPs more explicitly.

EBIPs investigated: peer instruction and the 5E model

Several EBIPs were introduced throughout the course (see syllabus in Supplementary Information); however, we opted to explore two of them in depth for this study in order to minimize time constraints on study participants during the interviews. We selected two EBIPs that displayed a range of attributes as outlined in Rogers' model: PI (Mazur, 1997) and the 5E Model (Bybee et al., 2006; Tanner, 2010).

In PI, an instructor poses a question to the class, usually in a multiple-choice format, and collects individual student responses via student response systems (e.g., clickers or flashcards). Depending on the distribution of responses, the instructor will then either provide an explanation of the question or have students pair up with their neighbors to discuss their reasoning and vote again individually. In the latter scenario, the instructor leads a discussion about the correct and incorrect answers. This practice can be implemented in a relatively short amount of in-class time (5–10 min) and requires minimal pre-class preparation by the instructor (i.e., low complexity).

The 5E Model, which is a research-based model for the design of curriculum, supports students in their constructing a new understanding of a concept by guiding them through questions in a learning sequence. There are five stages of this process each described by a word beginning with the letter "E": engage, explore, explain, elaborate, and evaluate. Each stage of the cycle serves as a foundation for the next, creating a coherent scaffold that frames a lesson or unit. The 5E Model is more complex to implement than PI, requiring more class time to complete each stage and often an entire class period or more to include all five E's. Moreover, the design of the activity associated with each of the 5 stages of the model requires more time and effort than preparing questions for PI.

As part of the introduction to these EBIPs in the course, future instructors first experienced PI and 5E Model as learners, as the course instructor incorporated both EBIPs into her lessons. Future instructors then had the opportunity to design their own activities for PI and the 5E Model and received feedback from both the course instructor and their peers. Additionally, all participants had to implement their PI activity during class as a required course component distinct from their mock lesson plan.

Positionality statement

The research team consisted of female chemical education researchers. ARK and LS were graduate students in the research group of MS. Both were interested in a career in academia and could identify with the experience of participants in this study since they had a limited preparation to teach and teaching experience. ELA was a postdoctoral scholar in MS research group with extensive experience in teaching chemistry at the postsecondary level and training learning and teaching assistants for chemistry courses. MS is a professor in chemical education with a research interest focused on instructional reforms in STEM environments in postsecondary settings. MS has developed and implemented numerous professional development programs around this research agenda, including the course that is used as the context for the study.

Data analysis

Data for Cohort 1 were analyzed in several rounds. In the first round, author ARK organized, reviewed, and summarized data. In a second round, author ARK summarized and compared the EBIP Teaching Toolcard responses. Author ELA helped established initial interrater reliability for these Teaching Toolcard summaries. These preliminary processes helped the researchers gain familiarity with the data and guide the direction of data analysis; these processes also served to build credibility via prolonged engagement with the data (Lincoln & Guba, 1985).

Following these initial reviews, a team of researchers (authors ARK, ELA, LS, and MS) worked together to develop a Case Summary Outline. The engagement of a team of researchers ensured that the data were being reviewed and organized from multiple perspectives. Each researcher was briefed on the research question and the theoretical frameworks, assigned a participant from Cohort 1, and provided with all of the corresponding raw data (e.g., interview transcripts, surveys, etc.; Additional file 1: Table S1) for their participant. Each researcher then provided suggestions on how to summarize and represent their case so that it would be grounded in the two theoretical frameworks and address the research question. After a whole team discussion, a template for the Case Summary Outline was finalized by authors ARK and MS (Additional file 1: Table S1). The final Case Summary Outline consisted of five sections: (1) a summary of the participant's teaching background (i.e., interest in teaching, themes expressed in their teaching philosophy, prior teaching experiences, and professional development participation); (2) the context of the course for their designed mock lesson plan (i.e., course name, class size, topic for the lesson); (3) their experience with EBIPs in general, and a summary of the participant's experience and thinking about (4) PI and (5) the 5E Model. The summaries of PI and the 5E Model included: prior experiences as a student and instructor with the practice, their thinking about the perceived attributes of the EBIP from the Teaching Toolcard, and reasoning from the post-interview supporting their decision to include or not the EBIP in their mock lesson.

Using the Case Summary Outline template, each member of the research team revisited their assigned participant to complete a Case Summary Outline for that instructor, leveraging all the data sources from their assigned participant (Additional file 1: Table S2). As data were reviewed and summarized into these outlines, researchers used a reference scheme to cite the corresponding data source to the information described within each section of the outline (see Additional file 1: Table S1 for complete reference list). This process allowed for triangulation across data sources and provided an audit trail to locate supporting evidence and quotes (Anney, 2014). The line number function in Microsoft Word was used for all documents to pinpoint the exact location of quote sources. Author ARK completed a Case Summary Outline for each of the five participants in Cohort 1. To establish interrater reliability and build consensus for each case, authors ELA and LS each completed two Case Summary Outlines and author MS completed one Case Summary Outline. Author ARK met individually with each team member to discuss and compare Case Summary Outlines for each participant. After these meetings, author ARK updated the Case Summary Outlines for Cohort 1 with additions and revisions from the team discussions upon establishing consensus of representation for each participant. Authors ARK and MS used the Innovation-Decision Process Model and the research question to guide and refine the Case Summary Outlines (Fig. 5). These refined Case Summary Outlines were reviewed by the research team member who had completed the respective case. Therefore, interrater reliability was established for the data at two stages in order to reach and confirm consensus, contributing to the credibility and confirmability of the analysis and findings (Anney, 2014).

Initial findings from the analysis of Cohort 1 informed and expedited the process for Cohort 2. Data for Cohort 2 was analyzed using the methods developed for Cohort 1. Author ARK repeated this process and compiled a Case Summary Outline for each participant using the same template developed for Cohort 1 (Additional file 1: Table S1). Author MS provided interrater reliability by reviewing the alignment between the data set for each participant and the Case Summary Outlines developed by author ARK.

Author ARK refined the Case Summary Outlines into Factor Summaries for each participant in Cohorts 1 and 2 (Fig. 5). In comparison to the Case Summary Outline which provided an overview of all the data for each participant, the Factor Summary highlighted data related to the research question and the two theoretical frameworks (Fig. 4).

Cross-case analysis was completed across participants' Factor Summaries to identify patterns in instructor's thinking that inform their decisions (Yin, 2009). The cross-case analysis focused on identifying patterns within the factors related to the Innovation-Decision Process Model. Characteristics of the individual and

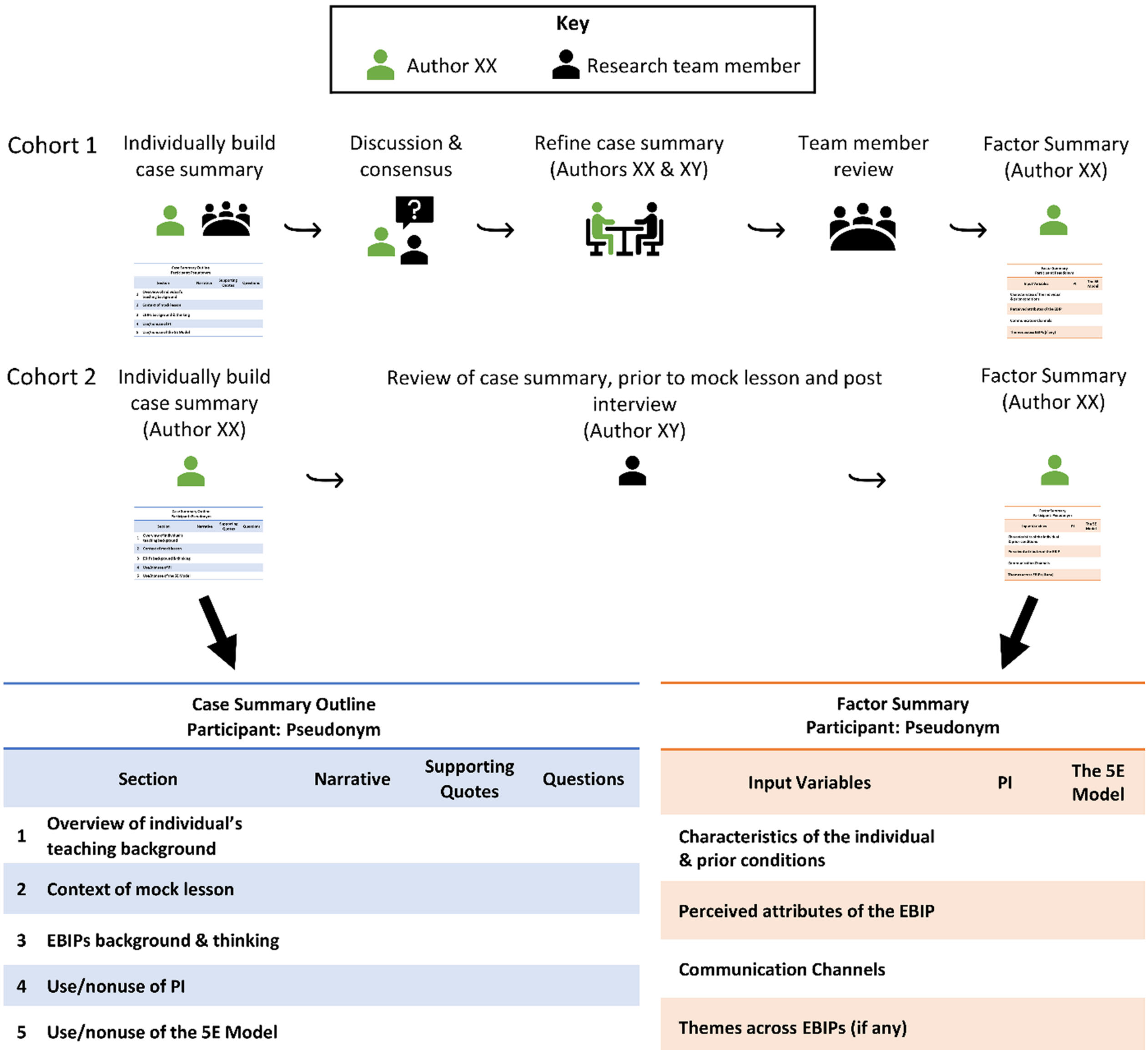

Fig. 5 Overview of data analysis and organization

prior conditions included comparison across participant's prior experiences of EBIPs, their thinking of EBIPs, and their teaching values. Author ARK independently coded the values expressed by participants in their teaching philosophy statements and in the member-checking portions of the post-interviews. Author ELA reviewed the data using the coding scheme established by author ARK. Authors ARK and ELA met to discuss and come to consensus on the teaching values present among participants. Using these teaching values, compatibility (one of the perceived attributes of the innovation, Table 1) was reviewed for all participants using the Factor Summaries. Due to the multifaceted nature of the compatibility attribute, authors ARK, ELA and MS met to discuss the compatibility factor and distinguished between compatibility with past experience, teaching values, and the combination of the two that lead to instructors' decision to use or not use the two EBIPs.

Results

We conducted a cross-case analysis with nine future STEM instructors to investigate their thinking about the implementation of two EBIPs: PI and the 5E Model. Using the TCSR Model and Roger's Innovation-Decision Process Model, we aimed to characterize the factors influencing instructors' decisions to adopt EBIPs in the

Table 3 Future STEM instructors' use of EBIPs PI and the 5E Model in their mock teaching lesson

Participant	Peer instruction	The 5E model
Charlie	✓	✓
Dakota	✓	×
Finley	✓	✓
Kennedy	✓	✓
Lincoln	✓	×
Morgan	✓	✓
Quinn	✓	✓
Skyler	×	×
Taylor	✓	✓

A checkmark denotes use of EBIP and an X denoted non-use

context of developing and implementing a mock teaching lesson as part of a graduate teaching methods course. The variation in the EBIPs that study participants chose to implement in their mock teaching lesson provided fruitful ground to explore these factors. Indeed, six study participants implemented both EBIPs, two implemented only PI, and one did not implement either EBIP (Table 3).

Our results are framed using the three factors influencing the rate of adoption of an innovation as described in Rogers' Innovation-Decision Process Model and are embedded in the TCSR framework (Fig. 4): characteristics of the individual and prior conditions, perceived attributes of the innovation (i.e., EBIP), and communication channels. We describe the factors within each of these variables that contributed to future STEM instructors' decisions to use PI and the 5E Model in their mock teaching lesson.

Characteristics of the individual and prior conditions

The first variable that relates to the rate of adoption in Rogers' (2003) Innovation-Decision Process Model accounts for the context and conditions that have been established for an individual before they enter the decision-making process. For the purposes of our study, the characteristics that describe the individual who is making the decision included an instructor's teaching values and their innovativeness, while the prior conditions consisted of an instructor's previous experiences with the EBIP.

Individual's teaching values

We summarize the themes present across participants' teaching values that were identified from our analysis (Table 4) and highlight the most common themes in the following sections.

Instructor and student roles in the classroom All nine participants felt that their role as instructor was to guide students and/or provide them with tools, but also believed that students should play an active role in their learning. In the post-interview, Skyler stated that they liked the combination of guiding and providing tools. This was also reflected in their teaching statement, where they equate tools with resources.

> *"My approach to teaching focuses on guiding students to understanding concepts and the connections between different subjects rather than attempting to transmit a specific series of facts … I take time at the beginning of each semester to explain the different resources available to students that may help them succeed … Through providing them with an array of resources, I hope to enable students to feel a sense of agency in their own learning." –Skyler, Teaching Philosophy Statement*

Building community in the classroom All but one of the participants (Quinn) explicitly stated that group activities help build community in the classroom. Participants felt that working in groups allowed students to collaborate and get to know one another, which they believed could make learning more fun. Participants also believed that group activities help students learn by articulating their understanding to one another and through exposure to others' perspectives. Charlie described how interactions in the classroom are important to students:

> *"I would like to design a classroom which is more interactive for the students […] so that the students can form connections with each other during class.… Group activities during the lectures where students work together to accomplish a set of problems can help students form these connections with each other, and form stronger connections with the material as they learn and reason through the concepts together." –Charlie, Teaching Philosophy Statement*

Along with engaging students with their peers, five participants described the importance of the instructor–student relationship. These participants described the importance of one-on-one interactions between the instructor and students and wanted to build a relationship by sharing about themselves in class. Morgan described the specific measures they would take to achieve this aim:

> *"These ambitious goals cannot be realized without a strong professor-student relationship. Forming this takes time and patience but can be facilitated through a few practical means. As a general rule, questions and contributions will be positively reinforced at any point during the class. Additionally, help during office hours was essential in my eventual*

Table 4 Future STEM instructors' teaching values

Theme	Teaching values	Description	Participants
Instructor and student roles in the classroom	The instructor's role is to guide and/or provide tools to students	The instructor serves as the guide and/or the provider of tools and/or resources	Charlie, Dakota, Finley, Kennedy, Lincoln, Morgan, Quinn, Skyler, Taylor ($N=9$)
	Students have agency/ownership in learning	Students have agency/ownership and are in part responsible for their learning	Charlie, Dakota, Finley, Kennedy, Lincoln, Morgan, Quinn, Skyler, Taylor ($N=9$)
Build community in the classroom	Build community through student–student interactions	Peer interactions support student learning	Charlie, Dakota, Finley, Kennedy, Lincoln, Morgan, Skyler, Taylor ($N=8$)
	Build a supportive learning community that values students as individuals	The instructor creates an environment where students feel comfortable and valued for sharing their ideas/questions, where accommodations are provided, and growth mindset is highlighted	Charlie, Dakota, Finley, Kennedy, Lincoln, Morgan, Skyler, Taylor ($N=8$)
	Build a community through instructor–student relationship	The instructor invests in building relationship with students (e.g., self-disclosure of personal experiences or one-on-one interactions with students)	Charlie, Dakota, Finley, Lincoln, Morgan ($N=5$)
Importance of applying learning	Practice helps students apply and learn knowledge/skills	Practice is an avenue for students to think about the content, articulate their understanding, make content connections between concepts, and apply the content	Charlie, Dakota, Finley, Kennedy, Lincoln, Morgan, Quinn, Skyler, Taylor ($N=9$)
	Promote students' development as humans for their future career/life	The instructor aims to make the course relevant to students' future career/life by connecting content to real world applications, providing real world examples, helping them develop transferrable skills (e.g., communication skills, collaboration skills) and promoting their affinity for science (e.g., promote identity as a scientist, increase science literacy)	Charlie, Dakota, Finley, Kennedy, Lincoln, Morgan, Quinn, Skyler ($N=8$)
Other	The instructor promotes mastery and curiosity	The instructor aims to promote mastery/curiosity rather than memorization/performance	Dakota, Kennedy, Lincoln, Morgan, Taylor ($N=5$)
	The instructor has passion for the job	The instructor has a passion for the content and/or for the teaching profession	Dakota, Kennedy, Lincoln, Skyler, ($N=4$)

mastery of organic chemistry as well as the means of establishing enriching relationships with professors. Support from a professor can make the difference in students sticking with a tough course or dropping out, and my aim is for each student to feel comfortable approaching me. To this aim I will have a mandatory office hour meet-and-greet so students know where my office is and will begin to feel more comfortable with me as their professor … The professor-student relationship is crucial to an effective learning experience." –Morgan, Teaching Philosophy Statement

All participants, except for Quinn, explicitly expressed their desire to build a supportive classroom environment that valued students as individuals. These participants stated that they wanted students to feel welcomed, comfortable asking questions and sharing their ideas, and develop growth mindsets. Kennedy exemplified this value in their teaching philosophy:

"I encourage students to participate in the classroom irrespective of whether or not they think they have the correct answer. This is because science is a field in which reasoning is arguably as or even more important than the outcome. I promote the classroom as a safe space for mistakes to be made as they can be learned from which is important as this helps students to develop a growth mindset." –Kennedy, Teaching Philosophy

Importance of applying learning All participants wanted to promote and support student agency by providing opportunities for students to practice applying their knowledge and skills in class. More specifically, all participants, except for Taylor, felt these applications should relate to the real world and/or students' future careers. Some participants, such as Quinn, explicitly connected these two values, stating that they valued the application of knowledge to the real world and believed that learning occurs when students can apply their knowledge and skills to new situations.

"Biology is not simply constrained to the classroom; it is an important facet in everyday life. … I would like my students to face complex cell biology or immunology issues in medicine, research or daily life and be able to assess and solve the problem. I want to give students the tools … I strongly believe that the best way for this goal to be accomplished is via active and engaged learning in the classroom … I believe that successful learning happens when you can actively apply your learning to new situations." –Quinn, Teaching Philosophy Statement

Overall, the participants had teaching values that aligned with student-centered teaching practices.

Innovativeness

Innovativeness refers to an individual's tendency to be early adopters of new ideas (Rogers, 2003). Participants displayed innovativeness of teaching practices at the start of the course as the majority recognized the effectiveness of EBIPs and were moderately to extremely motivated to implement them in the pre-survey (Fig. 6). Moreover, except for Lincoln, all participants believed that EBIPs were effective in promoting student learning. However, they generally lacked confidence in implementing these practices (Fig. 6).

Past experiences with EBIPs

Prior to the start of the course, participants were asked about their familiarity and experiences with PI and the

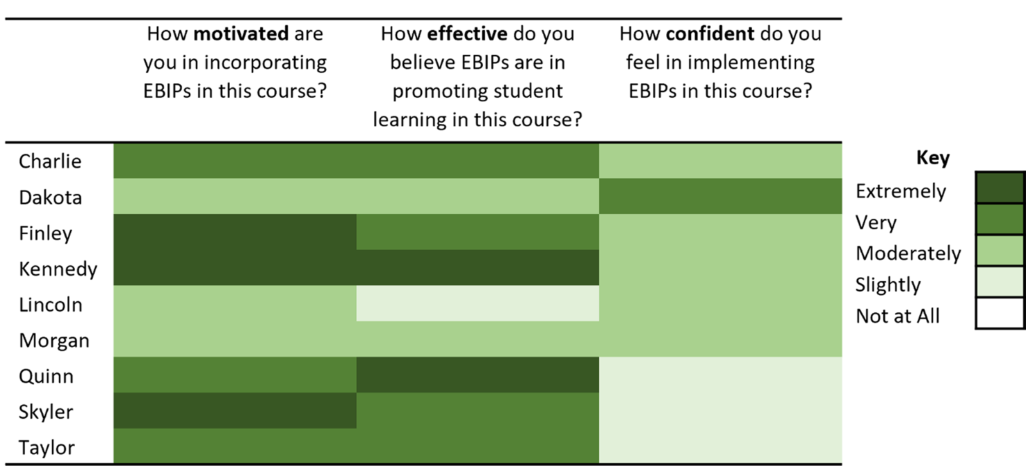

Fig. 6 Future STEM instructors' thinking at the beginning of the course about integrating EBIPs in their mock lesson

5E Model via the pre-survey (Cohort 1) or during the pre-interview (Cohort 2). Both cohorts were asked to confirm and expand upon these prior experiences in the post-interviews. Nearly all participants were familiar with PI and unfamiliar with the 5E Model. The familiarity in these practices stemmed from their previous experiences with the EBIP either as a student or as an instructor (Fig. 7).

Peer instruction All of the participants, except Charlie and Skyler, experienced PI as a student. Participants reported their experiences to be positive and beneficial to their learning. For example, Quinn felt that PI was part of the reason they enjoyed organic chemistry:

> *"I loved it [experiencing PI as a student]. I thought it was like a really good way to learn organic [chemistry]. I think that's why my organic [chemistry] experience was really good compared to most people." – Quinn, Pre-Interview*

Moreover, several participants mentioned a connection with PI (or a PI-related practice) in an instructional role, either as a teaching assistant (TA) or more informally as a tutor/mentor to students. Although Charlie was not initially familiar with the formal label of PI, they were able to relate the description of PI to their experiences as a TA and reported positive feelings about the practice.

> *"I was a TA for an organic chemistry class which used this [PI] and I think it was helpful, especially with TAs around in a bigger classroom … it gave a good impression because I could kind of see how it worked and see the teacher doing it. But again, I didn't really know, like it was called Peer Instruction. I just thought it was kind of like an extension of like clicker questions for her [the instructor]. So again, I guess, coming in and when I did learn about it, I was like, oh yeah, my professor would kind of do this like, I think it's good." –Charlie, Post-Interview*

Only Skyler did not have any prior experience with PI as a student or in an instructional capacity. They were familiar with the use of clickers and polls which they had seen in departmental seminars rather than in the context of a classroom. Skyler described their experience as a student to be mostly didactic lecture-based.

The 5E model Participants were mostly unaware of the 5E Model. In fact, no one reported having experience with the 5E Model as a student prior to the start of the course. However, after a formal introduction to the EBIP in the course, Finley realized that the 5E Model was a large part of their previous chemistry coursework and thought those experiences were positive:

> *"This tool [the 5E Model] also aligns well with my previous experiences in the classroom. While I did not know it at the time, most of my undergraduate chemistry lessons were structured with [the] 5E [Model] worksheets that were completed in small groups. I had a good experience with this lesson format." –Finley, Post-Interview*

Similarly, Kennedy and Lincoln later described having experienced related practices, such as worksheets, or were able to identify aspects of the 5E Model in projects they had completed. Only Lincoln reported having negative experiences with worksheets as a student and associated those worksheets to the 5E Model; this association is logical since the 5E Model was presented as a worksheet in the course.

> *"[Relating the 5E Model to worksheets.] I suck at worksheets. I'm not good at them. I don't understand questions that well apparently when I read them, I*

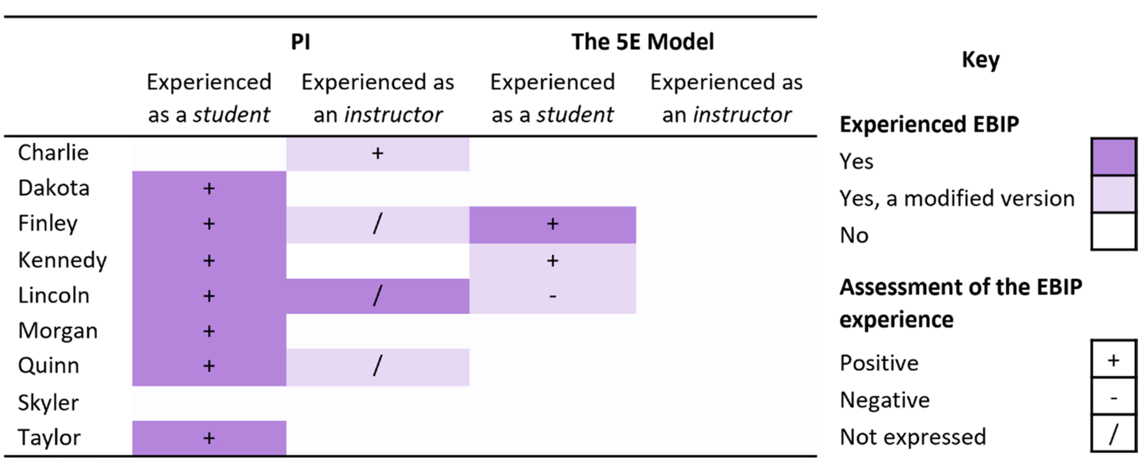

Fig. 7 Future STEM instructors' past experiences with PI and the 5E Model before the course

> *get sidetracked … I don't do well with worksheets." –Lincoln, Post-Interview*

None of the future instructors experienced the 5E model in a teaching capacity.

In summary, the future instructors were familiar and enthusiastic about EBIPs, thanks to mostly positive past experiences they had as a student and/or instructor with the EBIPs targeted in this study. They also held values about teaching that are aligned with EBIPs. Consequently, the characteristics of these future instructors and their prior conditions were set to promote their favorable engagement in the innovation decision process.

Perceived attributes of the EBIP

Whereas the "Characteristics of the Individual and Prior Conditions" factor is solely about the individual person, the perceived attributes concern the individual's perception of the innovation. These factors require an individual to reflect upon the properties of the innovation and determine their personal view of the innovation. In this study, we explored three perceived attributes of EBIPs: compatibility, relative advantages, and complexity of the EBIP.

Compatibility

Compatibility refers to participants' perception of the EBIP as being consistent with their existing values (i.e., teaching values in this study) and past experiences. We found that one or both of these aspects heavily influenced the study participants' decision to implement one or both EBIPs in their mock lesson (Fig. 8).

Compatibility with previous experiences as a student For one participant, their past experience as a student was critical to their decision to implement the EBIP in their lesson. Taylor recalled experiencing frustration as a student when they did not receive immediate feedback on their performance. Once they learned in the course that immediate feedback was a key feature of PI, they chose to implement it.

> *"I think with the Peer Instruction, I was sort of indifferent on its utility, but within the class [the graduate course in which participants were recruited from, the] professor emphasized, like not only is it an opportunity for students to engage with each other, but they can actually see that their performance is improving. And I thought that aspect—students can see progression—was really the tipping point for me. Cause I think as a student, I encountered many instances where I tried to do something, but I didn't get immediate feedback before I tried it again. So, having immediate feedback on how I did and then seeing like, if I did get it wrong, these practices helped me change that. [And] that emphasized the benefits and overall, my motivation to use Peer Instruction." –Taylor, Post-Interview*

Compatibility with teaching values There were many instances in which participants' decisions were informed by their teaching values (Fig. 8). There was no evidence that these teaching values were related to participants' past experiences as a student or instructor. For example, Morgan decided to use the 5E Model because it aligned with their value that students learn in a community as well as their perception of instructor and student roles in the classroom. When asked to expand upon their responses to the post-survey about which factors informed their decision, Morgan stated:

> *"I'd say that a big one was the compatibility alignment with my values/beliefs of teaching and the idea that students can learn exceptionally well from other students and that having the opportunity to explain, that make students comfortable with each other helps them … also being able to teach someone else is a really important sign of that you actually know the material well … And then also it kind of puts me in a role where instead of simply telling them things, I get to sort of watch them uncover it on their own and be there alongside them for the ride, herd them along the way and then kind of nudge them back into the center whenever they start to veer off to the side … I really enjoy that role. I thought that this worksheet was conducive for that." –Morgan, Post-Interview*

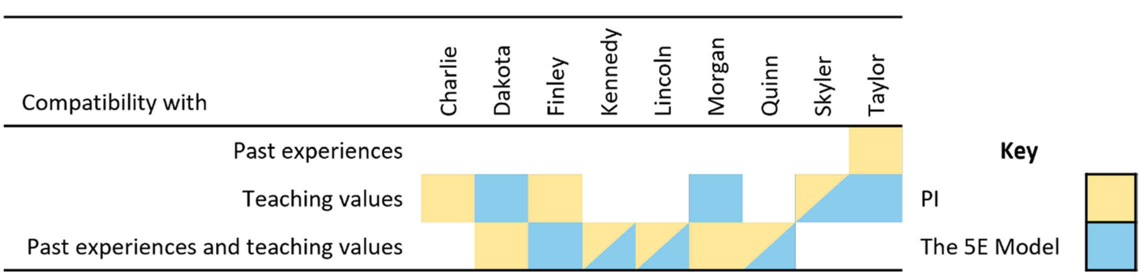

Fig. 8 Types of compatibility influencing future instructors' decisions about PI and the 5E Model

Compatibility of previous experiences and teaching values In many instances, participants' compatibility was framed as the combination of their past experiences and teaching values. Indeed, participants drew upon and made connections to their past experiences when discussing their teaching values. For example, Lincoln had negative experiences learning with worksheets as a student (see quote above), which is the format that was used in the course to enact the 5E Model. Further, Lincoln valued being hands-on and in control as an instructor. They described teaching and learning as a "team effort", in which the instructor was the expert. Lincoln felt that giving students worksheets was a missed opportunity for students to learn from the expert.

> *"I don't do well with worksheets. So, I personally would not use worksheets like that in my own course, moving forward, just because I feel as if I can convey the information better speaking it. And I feel like there's more interaction between you and I versus you and a paper.... Rather than someone like guiding you through it, you have to be the driver of your own learning there in that moment. I don't know, personally, if a teacher did that to me, that seems like a substitute teacher worksheet ... I don't see the value of them [worksheets] during class time ... where you, as an instructor are there to provide for students. I feel like giving them a worksheet at that time is kind of robbing them from like real interaction with a teacher." –Lincoln, Post-Interview*

Lincoln drew upon their own learning preferences as well as their view of their instructional role to inform their instructional decision not to use the 5E Model in their teaching.

Relative advantages

Relative advantages refer to the perception that EBIPs are more effective than other teaching practices. Our analysis indicates that participants considered the relative advantages of an EBIP when deciding whether or not to implement it. For example, Finley, Taylor, and Quinn performed a cost–benefit analysis when making the decision to implement the 5E Model. They indicated choosing to implement the 5E Model despite its perceived weaknesses, as the following quote from Finley illustrates:

> *"It's the basis of what I structured my lesson upon, so even though I found it difficult to use and that it required resources, I was willing to dedicate that time ... because I found the value of the tool to be greater than the resources that I would have to put into prepping it." –Finley, Post-Interview*

On the other hand, Dakota felt that, while the 5E Model could be useful under certain conditions, the disadvantages exceeded any benefits and thus decided not to implement it:

> *"The main thing was just the time constraints ... And just balance time spent on something versus the material covered overall ... it just felt too time consuming to really implement ... If it was possible to have a theoretical number of knowledge gained per minute, I feel like [the] 5E [Model] you would be low on that ... it feels a little more in depth and maybe if there's like a very important and difficult to understand topic, I might use it and devote a whole class to it or something. I would probably just use it sparingly in a full course lecture, maybe once or twice throughout the semester."*
> *–Dakota, Post-Interview*

Communication channels

The final variable relating to rate of adoption in the Innovation-Decision Process Model is the communication channel. This is the means of message exchange between a source (e.g., an individual or institution that originates a message) and a receiver. The course that the participants were enrolled in was a formal, interpersonal communication channel that provided content knowledge and experience with both of the EBIPs explored in this study. Three influences of this formal communication were apparent in our data: (1) the course reinforced and built upon participants' prior experiences with EBIPs; (2) the course provided participants with opportunities to experience the EBIPs as a student and as (3) an instructor.

The course reinforced and built upon participants' prior experiences with EBIPs Several participants who had prior experiences with the EBIPs indicated that the course helped to confirm and validate their perspectives of the practice. In particular, participants indicated that the presentation in the course of evidence showing the effectiveness of the EBIP validated their general feeling that the EBIP was effective for them as student.

> *"I can be like kind of aware of those benefits [of PI] myself from my experience, but being told and being taught these are the benefits of this tool within a course makes me feel more confident about the tool itself rather than my own experience purely"*
> *–Finley, Post-Interview*

The formal introduction of the 5E Model in the course also helped Finley recognize that their positive learning experiences in their undergraduate courses stemmed from the use of that instructional strategy:

> *"After being introduced to [the] 5E [Model] within the course, I've formed an appreciation for how my undergraduate classes are structured, and then I've seen more value using that tool within a classroom setting." –Finley, Post-Interview*

Furthermore, experiences in the course expanded instructors' views of EBIPs from their past experiences. For example, Lincoln and Taylor described a newfound understanding of PI. Taylor's past experience with PI seemed to only involve submitting an answer via clickers before the instructor displayed the correct answer, excluding the student discussion component.

> *"My experiences with peer instruction type questions: they were on the shorter clicker question side, where we would just submit an answer and then as a student, I just saw the right answer at the end, and some elaboration as to how to get there. But if I didn't know exactly how the calculation worked, even after my instructor performed it, then I just didn't know at the time, like how to improve on it. But in the [study context] class, when [the] professor went over the full steps of how peer instruction is supposed to be implemented, I found that it turns like that odd clicker question for participation more meaningful as you have a better opportunity to have students engage with each other, to try to explain what is going on, encounter different perspectives." –Taylor, Post-Interview*

The course provided opportunities to experience EBIPs as a student Participants were able to experience the EBIPs first-hand as learners in the course. Many participants were not initially familiar with the 5E Model, and therefore the course was their first introduction to this EBIP. Morgan and Taylor elaborated on the benefits they perceived as learners through this classroom experience. In particular, Morgan reflected on this process with excitement, even remembering during the post-interview both the topic and how the 5E Model worksheet scaffolded their learning progression.

> *"My initial introduction to the technique within the course was the lecture, [the instructor] had us go over that [the] 5E [Model] worksheet. It was cocaine on the receptors! I thought that was really cool. That was really effective way to scaffold in the information and like progressively build on a story .... it's so methodical and it progresses so like gradually that you can like start with no knowledge of the topic, basically and teach yourself by the end of the worksheet." –Morgan, Post-Interview*

Similarly, Quinn said they did not necessarily find the 5E practice to be useful to them because they were familiar with the topic used for the 5E Model worksheet, but reflected on how the 5E Model practice helped their classmates learn. Beyond the initial introduction to the 5E Model in the course, participants also found value in experiencing EBIPs as a student during their classmates' lesson demonstrations. For example, Skyler recalled how Quinn's lesson, which included PI and the 5E Model, was effective in helping them to grasp an unfamiliar topic as a learner.

> *"The relative ease with which I was able to grasp Quinn's subject, despite not having touched biology with a 10-foot pole in six years, helped me realize how well EBIPs can teach information; this one experience was backed up by the papers we read and the statistics backing them." –Skyler, Post-Survey*

The course provided opportunities to experience EBIPs as an instructor During the course, participants were provided with the opportunity to practice designing both a PI and 5E Model activity. Additionally, the course's lesson on PI required participants to practice implementing their PI activity. Participants found this low-stakes practice to be helpful as it built familiarity and confidence with using the EBIP as an instructor. Participants received feedback from their peers and the course instructor on their activity designs and implementation, which participants expressed was particularly beneficial to their experience. Charlie commented on how the combination of practice and feedback helped them decide to use the 5E Model.

> *"I think the ... [practice with the 5E Model in the course] was a big thing for me just because it got me to create it and see how it worked, and see how I could connect it to the topic ... I think trying it out and just seeing how it worked and then getting a little bit of [instructor] feedback too and feedback from the students." –Charlie, Post-Interview*

Furthermore, the course helped participants see the effectiveness of active learning. For example, at the beginning of the course, Lincoln felt that EBIPs were only slightly effective in promoting student learning. However, after completing the course, Lincoln credited the active learning portion of their lesson rather than the lecture portion as the reason their peers learned from their lesson.

> *"I don't know if anybody still comprehends a lot of information [from my lesson], but if they were*

to comprehend the information, it would not be because of the lecture. It would be because of the active learning." –Lincoln, Post-Interview

Discussion

We explored factors that inform future STEM instructors' decisions to implement two EBIPs: PI and the 5E Model. Specifically, we explored factors inherent to individuals and the specific EBIPs using the TCSR model and Innovation-Decision Process Model (Fig. 4). We organized our results as outlined in Rogers' Innovation-Decision Process Model (2003): characteristics of the individual and prior conditions, perceived attributes of the innovation, and communication channels. While each of these factors contributed to future STEM instructors' EBIP adoption decisions, their personal experiences as student and/or instructor underlined the influence of most of these factors and thus their decisions to implement one or two of the EBIPs in their mock lesson (Fig. 9).

Past experiences with the EBIP contributed to instructors' decisions to adopt the EBIP

Previous work has described teacher knowledge akin to student's prior knowledge, asserting that it is just as important to understand that instructors are not blank slates (Oleson & Hora, 2013). Indeed, their experiences as students, instructors, and in their personal lives shape their thinking. Our data support an association between an instructor's decision to adopt an EBIP and the emotional valence (i.e., positive or negative feelings) of their prior experiences with that EBIP (blue arrow in Fig. 9). For instance, several participants had positive past experiences with PI and/or the 5E Model and subsequently used the EBIP(s) in their mock lesson. Similarly, one participant had a negative experience with the 5E Model and chose to not include it in their mock lesson. Interestingly, another participant did not have any prior experience with either EBIP and did not use either in their mock teaching lesson. Previous work has reported similar conclusions regarding the relationship between the compatibility of past experiences and EBIP adoption decisions (Montfort et al., 2012; Turpen et al., 2016). These findings confirm those of previous studies and further highlight the perception stage of Rogers' Innovation-Decision Process Model and how the attitude towards the innovation can and indeed does factor into an individual's adoption decision.

As our participants were future STEM instructors and had little to no formal teacher training, it makes sense that they would draw upon their past experiences in their teaching decisions—a phenomenon that Borg (2004) refers to as "an apprenticeship of observation" (Andrews & Lemons, 2015; Fukawa-Connelly et al., 2016; Oleson & Hora, 2013; Powell, 1992; Turpen et al., 2016). Further, researchers have found that instructors who experienced EBIPs as a student are more likely to tryout or adopt these practices as an instructor (Lund & Stains, 2015; Yik et al., 2022a, 2022b). However, these studies investigated this link by looking at EBIPs as a broad collection of teaching methods, rather than treating each practice individually. Thus, our findings add specificity to the previous literature as our participants adopted the specific EBIPs they had experienced as learners.

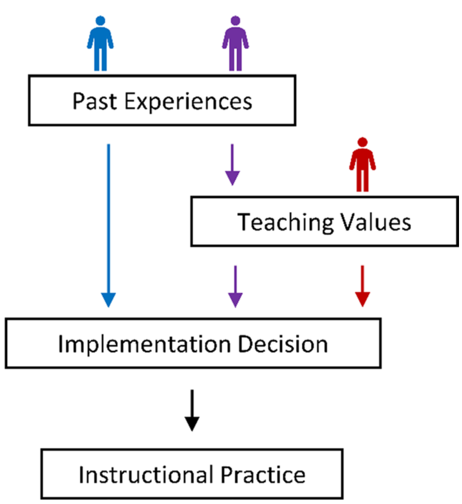

Fig. 9 Future STEM instructors' pathways leading to EBIP implementation

Teaching values, which are anchored in instructors' past experiences, contributed to their decisions to adopt an EBIP

Our future instructors' perception of the compatibility of an EBIP with their teaching values was the major driving force behind their teaching decisions (red arrow in Fig. 9). Indeed, all the participants considered and brought up their teaching values as a reasoning behind their decision to implement or not the EBIP (Fig. 8). These findings add to previous work that has shown perceived compatibility to be an important factor in instructors' decisions to adopt innovations (Blumberg, 2015; Genné-Bacon et al., 2020; Montfort et al., 2012; Turpen et al., 2016). Our findings also underscore the link between Teacher Thinking and Instructional Practices in the TCSR model. The relationship between instructors' beliefs and practices has been previously described in the literature (e.g., Borrego et al., 2013; Gibbons et al., 2018; Idsardi et al., 2023; Kraft et al., 2023; Mesa et al., 2014; Popova et al., 2020; Yerushalmi et al., 2010). For example, a national survey of over 1,000 chemistry instructors conducted by Gibbons et al. (2018) provided evidence for the link between instructors' thinking and practices as they found significant differences among faculty thinking between instructors using different instructional styles: instructors in the interactive and small group styles held student-centered beliefs about learning whereas those in the lecture-based styles held teacher-centered beliefs about learning. Moreover, Yerushalmi and colleagues (2010) investigated how 30 physics instructors' beliefs and values influenced the type of physics problems they gave to students in an introductory course. Their findings showed that physics instructors articulated goals and features of problems that aligned with the literature supporting student learning. However, these instructors did not use these features because of stronger held values of concern for clarity of presentation and reducing student stress particularly on exams. Our findings further support a relationship between instructors' thinking, specifically the compatibility with their teaching values and their instructional practices.

Often, the teaching values that future instructors described were shaped by their experiences as learners themselves (Fig. 8). Participants appeared to reflect on their prior learning experiences to evaluate what was productive or inhibitive to their learning. In some cases, participants wanted to carry on positive ideas they benefited from as a student, such as forming a strong instructor–student relationship (e.g., Morgan). Others wanted to improve upon their past experiences in their own instruction by including more opportunities for practice and feedback on learning (e.g., Taylor). Overall, the values expressed by our participants generally aligned with student-centered teaching. Our study therefore confirms and provides a more in-depth understanding of the links present in the TCSR Model between Personal Factors, Teacher Thinking Factors, and Instructional Practices. In particular, it highlights the critical role that past experiences as students and/or instructors play in shaping the teaching values these future instructors hold and that participants consciously draw from these values to evaluate their adoption of EBIP (purple arrows in Fig. 9). Our results also add some nuances to the findings from a study by Chapman and McConnell (2018). In this study, the authors explored factors that promote student-centered teaching beliefs among geoscience graduate students and postdoctoral scholars. They found that the most influential factor was students' participation in semester-long professional development programs; these students had more student-centered beliefs than those with little professional development. In our study, the participants had limited participation in professional development programs prior to their enrollment in the course (Table 2), and yet demonstrated student-centered values. While our study participants are likely biased towards these views since they voluntarily engaged in this non-mandatory pedagogical course, our findings point to the need to explore and control for the role of past experiences in shaping teaching values when exploring the impact of engagement in professional development programs on beliefs about teaching and learning.

Professional development reinforced instructors' past experiences and provided new experiences that inform their decision to implement EBIPs

Our findings highlight the influence of professional development as a communication channel in the adoption of EBIPs. The positive influence mostly stems from the ability of the professional development program (i.e., the course) to leverage past experiences and create new experiences that participants can draw from to make their decision to adopt an EBIP (Fig. 10).

First, the results of our analysis indicate that professional development can reinforce and help participants make meaning of prior experiences as students or instructors. Participants in our study who had previous experiences with the EBIPs were able to make sense of and build upon their personal perceptions of the EBIPs when presented in the course with evidence/data to support the EBIP. Indeed, participants expressed that the information presented in the course provided them with a stronger rationale to support their use of EBIPs beyond their own experiences as learners and/or instructors.

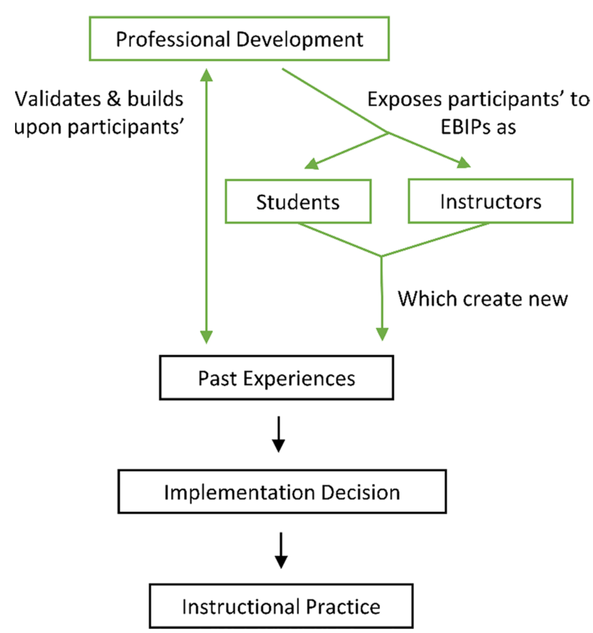

Fig. 10 Professional development influences on participants past experiences

Second, our findings demonstrate the need to provide authentic, positive experiences to participants during professional development programs, as these experiences become drivers of decisions to adopt innovative practices. In our study, the course exposed participants to the EBIPs in two ways: as a student and as an instructor. While most participants had prior experience with PI as students, few had experienced the 5E Model as students and most of these prior experiences were only loosely related to the 5E Model. During the course, the participants learned about a science concept that was foreign to most via a worksheet designed based on the 5E Model. As participants indicated, this authentic student experience with the 5E Model created a foundation of personal experience that participants drew from to make their decision to adopt this EBIP. This pattern of exposure through authentic experience and building upon these experiences repeated the validation pattern our participants described with PI. The course also exposed participants to EBIPs from an instructor's perspective. Participants were able to design, implement, and receive feedback on each of the EBIPs, which they found to be critical in building their confidence for using the EBIPs in their teaching. Previously, one study reported a high rate of EBIP adoption among instructors who had been enrolled in a professional development program that provided similar support (Wieman et al., 2013). This was in stark contrast to previous work which demonstrated high rates of attrition in EBIP-adoption among faculty who lacked feedback and support during their implementation stage (Henderson et al., 2012). Our research builds upon the work of Wieman et al. (2013) by elaborating on the kind of support that increased instructors' adoption of EBIPs, namely opportunities to practice with the EBIPs in a low-stakes setting and receiving feedback on that practice. This aligns with recommendations made in previous studies that looked to promote EBIPs adoption with new instructors (Andrews & Lemons, 2015; Turpen et al., 2016).

Implications for research

First, this study illustrates the long-term impact that the current implementation of student-centered teaching practices in STEM courses can have in a decade and beyond. Some of the current students in these courses will become instructors within 10–15 years. This study along with other studies in the literature indicate that these experiences have a strong potential to drive these instructors' decision to implement identical or similar instructional practices in their courses and to promote teaching values aligned with student-centered practices (e.g., Oleson & Hora, 2013; Powell, 1992; Seithers et al., 2020). However, our findings also indicate that the emotional valence of instructors' past experiences with student-centered practices play a role. It would be interesting to explore with a larger, more diverse sample the emotional valence of instructors' past experiences and how these relate to the development of their teaching values and EBIP adoption decisions.

Second, we noticed that the relative advantages of the EBIP was a weak influence in our future instructors' decision to implement the EBIP. This is in contrast with the findings from another study which explored characteristics of innovations that lead to successful dissemination. They reported that relative advantages was the most influential characteristic of the innovation (Bourrie et al., 2014). However, it is important to note that the participants in that study were part of an expert panel which consisted of principal or co-principal investigators on STEM education grants. It is possible that the novice status of the participants in our study played a critical role in the factors and influences they chose to attend to when making a decision. It may be that as instructors gain knowledge and expertise in teaching, they experience a shift in the factors most influential in their decision-making. It would thus be interesting to explore the differences in factors contributing to expert and novice instructors' decisions to adopt EBIPs. Moreover, given that both personal (as demonstrated in this study) and contextual factors contribute to instructors' teaching decisions, future research should collectively explore the weight of these contributions on instructional decisions as instructors' teaching experience increases and academic appointment evolves.

Recommendations for professional development programs

The main finding emerging from this study is the key role that personal experiences play in instructional decisions. While this role of personal empiricism has been previously reported in the literature (Andrews & Lemons, 2015; Cooper & Stowe, 2018), our study highlights the need to consider and leverage these personal experiences as part of our effort to propagate and increase adoption of student-centered practices. Building on the findings from this study, we provide below a set of recommendations for the design of effective professional development programs focused on student-centered practices.

Validate participants' past experiences with EBIPs with evidence of their effectiveness

This study showcases the positive impact of validating participants' prior experiences with EBIP with empirical evidence of their effectiveness. While research indicates that showing empirical evidence for the effectiveness of instructional practice does not lead to the adoption of these practices (Andrews & Lemons, 2015), our study suggests that it is still valuable to show these data as they can help reinforce and validate personal feelings about an instructional strategy's effectiveness. This validation enriches an instructor's personal empiricism which, in this study, led to the adoption of the practice. It might thus be strategic for professional development facilitators to survey their participants prior experiences with various instructional practices and/or curriculum and showcase during the professional development program evidence supporting identical or similar practices/curriculum.

Provide participants with authentic and positive experiences with EBIPs both in a student and instructor role

Our study reinforces findings from the literature about the necessity to provide authentic experiences as a learner and instructor with the instructional practice(s) targeted by the professional development program (e.g., Beane et al., 2020; Cardamone & Dwyer, 2023; Eddy et al., 2019). We suggest providing a student-experience first when introducing a practice that is new to the majority of the audience and then building upon that foundation by sharing formal descriptions, structures, scaffoldings, and evidence supporting the practice. Further, whether the practice is new to most of the audience or the audience is already familiar with it, it is critical to have them experience it as an instructor in the safe space that a professional development program provides. The experience along with feedback from peers and facilitators will all contribute to enhance participants' confidence to implement the practice.

Engage participants in reflecting on how their past experiences with EBIPs and experiences within the professional development program shape their teaching values

Our findings, similar to prior studies (e.g., Borrego et al., 2013; Gibbons et al., 2018; Idsardi et al., 2023; Kraft et al., 2023; Mesa et al., 2014; Popova et al., 2020; Yerushalmi et al., 2010), emphasize the key role that teaching values play in an instructor's teaching decision-making and thus the need to attend to these during training. Professional development facilitators should thus provide opportunities for their participants to reflect on their past experiences as students and instructors, with and without EBIPs, and have them explicitly describe how these experiences has shaped their values. Moreover, participants should systematically reflect on how their experiences within the professional development program is helping refine their teaching values.

Limitations

The findings of this study should be considered in light of the following limitations:

1. Participants were voluntarily enrolled in the graduate course about teaching methods. It is possible that graduate students with limited or negative experiences with EBIPs chose not to enroll in this course. Therefore, our sample may not reflect the broader population of future STEM instructors. Consequently, we do not claim generalizability of these findings to future STEM instructors as a whole.
2. The course in which participants were recruited from was impacted by the COVID-19 pandemic during data collection. Cohort 1 experienced the course in an online format whereas Cohort 2 experienced it in person. While the content largely remained the same, this context could have impacted future instructors in a variety of different ways. However, from the similarities described by participants about the impact of the course, we did not directly observe any notable differences between the two cohorts.
3. This study captured the short-term adoption of EBIPs in the context of a mock lesson, rather than sustained adoption of EBIPs over time in a formal teaching environment. The context of the course and the implementation of the mock lesson within the course setting may have influenced their choices for adoption of EBIP. Of note, when pressed for whether they felt pressured by the instructor of the course to include EBIP in their mock session, all participants indicated that they did not experience such pressure. In light of the context in which adoption of EBIP was studied, we do not claim generalizability of these findings to STEM instructors across various teaching contexts.
4. As is the nature of capturing individual's thinking, we were limited to what they expressed through verbal and written prompts; thus, we captured what participants felt to be most salient in their decision-making, but there may have been other factors that were not explicitly/consciously noticed by participants.

Conclusions

Many have asserted that instructors "teach how they were taught." Our findings lend partial support to this statement, yet notably we found that this was not always the case as several of our participants used their experiences as students to do just the opposite. Further this notion of instructors mirroring their learning environments is often implied to be negative, but our results showed how this prior experience can in fact positively align with calls for educational reform. As EBIPs and instructional practices continue to be adopted, recent generations of students are therefore being exposed to different kinds of teaching experiences. This is to say that students have more exposure to other instructional practices than lecture alone and draw upon those experiences to inform their own teaching. Thus, our approach to understanding the factors influencing instructional decisions must expand to consider the prior experiences of instructors.

Abbreviations

EBIPs Evidence-based instructional practices
CURE Course-based undergraduate research experience
PARE Prevalence of antibiotic resistance in the environment
PI Peer instruction
STEM Science, technology, engineering, and mathematics
TCSR Teacher-centered systemic reform

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40594-024-00478-3.

Additional file 1. Supplementary Materials. The file contains the graduate coruse syllabus, the pre and post surveys, the pre and post-interview protocols, the template for the Teaching Tool Card, **Table S1** (Case sumamry outline), **Table S2** (Categorization of Data Sources Used to Develop the Case Summary), and **Figure S1** (Data Collection Timeline for this Study).

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Author contributions

ARK and MS designed the study, data collection materials, and collected data. ARK, ELA, LS, and MS analyzed the data. ARK, ELA, MS contributed to the writing of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare that they have no competing interests.

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