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Authors

Rozhenkova, Veronika
Snow, Lauren
Sato, Brian K
et al.

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Limited or complete? Teaching and learning conceptions and instructional environments fostered by STEM teaching versus research faculty

Veronika Rozhenkova[1*], Lauren Snow[2], Brian K. Sato[3*], Stanley M. Lo[4] and Natascha Trellinger Buswell[5]

Abstract

Background An instructor's conceptions of teaching and learning contribute to the establishment of learning environments that may benefit or hinder student learning. Previous studies have defined the continuum of teaching and learning conceptions, ranging from limited to complete, as well as the instructional practices that they help to inform (instructor-centered to student-centered), and the corresponding learning environments that these conceptions and practices establish, ranging from traditional to student-centered. Using the case of one STEM department at a research-intensive, minority serving institution, we explored faculty's conceptions of teaching and learning and their resulting instructional practices, as well as uncovered their perspectives on the intradepartmental faculty interactions related to teaching. The study participants were drawn from both teaching-focused (called Professors of Teaching, PoTs) and traditional research (whom we call Research Professors, RPs) tenure-track faculty lines to identify whether differences existed amongst these two populations. We used interviews to explore faculty conceptions and analyzed syllabi to unveil how these conceptions shape instructional environments.

Results Overall, PoTs exhibited complete conceptions of teaching and learning that emphasized student ownership of learning, whereas RPs possessed intermediate conceptions that focused more on transmitting knowledge and helping students prepare for subsequent courses. While both PoTs and RPs self-reported the use of active learning pedagogies, RPs were more likely to also highlight the importance of traditional lecture. The syllabi analysis revealed that PoTs enacted more student-centered practices in their classrooms compared to RPs. PoTs appeared to be more intentionally available to support students outside of class and encouraged student collaboration, while RPs focused more on the timeliness of assessments and enforcing more instructor-centered approaches in their courses. Finally, the data indicated that RPs recognized PoTs as individuals who were influential on their own teaching conceptions and practices.

Conclusions Our findings suggest that departments should consider leveraging instructional experts who also possess a disciplinary background (PoTs) to improve their educational programs, both due to their student-centered impacts on the classroom environment and positive influence on their colleagues (RPs). This work also highlights the need for higher education institutions to offer appropriate professional development resources to enable faculty

*Correspondence:
Veronika Rozhenkova
vrozhenk@uci.edu
Brian K. Sato
bsato@uci.edu
Full list of author information is available at the end of the article

to reflect on their teaching and learning conceptions, aid in their pedagogical evolution, and guide the implementation of these conceptions into practice.

Keywords Active learning, Conceptions of teaching and learning, Learning environment, Instructional practices, Research faculty, STEM education, Student-centered learning, Syllabus analysis, Teaching faculty

Introduction

The state of teaching effectiveness in undergraduate education is of primary interest to stakeholders in STEM disciplines. The benefits of inclusive pedagogies, such as active learning and other evidence-based teaching practices, are being considered in numerous venues ranging from formal peer reviewed research (e.g., Borda et al., 2020; Freeman et al., 2014; Nguyen et al., 2021; Theobald et al., 2020) to opinion pieces in popular press (e.g., McMurtrie, 2019; Supiano, 2022). There is a general desire to improve undergraduate student outcomes, especially for minoritized students (which we define as Black, Latinx or Hispanic, and Indigenous peoples based on their underrepresentation in higher education compared to the general population), who in particular have been shown to benefit from evidence-based instructional practices (Freeman et al., 2014; Harris et al., 2020). Recently, however, there has been more of an emphasis on instructors' perceptions regarding these new advances in teaching and learning and instructors' desire, or lack thereof, to implement them (Andrews et al., 2019; Emery et al., 2021). In this work, we aim to contribute to this discussion by exploring whether instructor conceptions of teaching and learning are related to the consideration and implementation of evidence-based teaching practices, and how faculty position type may relate to these conceptions and practices.

The study campus is found within a doctoral degree granting, research-intensive, state university system in the western part of the United States, which is home to a tenure-track teaching-focused faculty line, referred to as the Professor of Teaching (PoT) (Harlow et al., 2020). PoTs, who are embedded with traditional tenure-track research-focused faculty (which we will refer to as Research Professors or RPs) in their disciplinary departments, are expected to carry a teaching load approximately twice that of RPs. In addition to their instructional responsibilities, PoTs participate in education-focused scholarly activities (e.g., discipline-based education research) and service responsibilities (e.g., university committee service or educational outreach activities). To better understand the teaching and learning conceptions and practices of STEM faculty in these two types of positions (PoTs and RPs), we present a study of professors in the teaching- and research-focused lines who are all members of one STEM department at a large-enrollment, research-intensive (R1 designation according to the Carnegie Classification system), minority-serving (a designation provided by the United States Department of the Interior for universities that serve a significant number of students from minoritized populations) university.

Our research questions are as follows:

1. What are Professors' of Teaching (PoTs') conceptions of teaching and learning and how do these conceptions inform the development of their instructional environments?
2. What are Research Professors' (RPs') conceptions of teaching and learning and how do these conceptions inform the development of their instructional environments?
3. If teaching and learning conceptions and instructional environments vary between PoTs and RPs, are PoTs influencing their RP colleagues in these areas?

In our research, we may expect teaching-focused faculty to have more sophisticated (or complete) teaching and learning conceptions. Prior work characterizing PoTs highlights that while they are primarily trained within their discipline, they are likely to have extensive prior experience as instructors, have participated in pedagogical professional development opportunities, and/or conducted discipline-based education research (Harlow et al., 2020). In addition, their position specifications highlight an expectation of teaching excellence and contribution to scholarship and service related to the university's teaching mission. As such, they are likely more familiar with evidence-based teaching practices and their implementation and have more of a professional incentive to reflect on their teaching.

As the ability to transform STEM higher education to ensure the equitable participation of all students relies in large part on the instructor, it is important to understand instructors' conceptions of teaching and learning, as well as how these influence their teaching practices and the instructional environments they create. By comparing these conceptions among teaching- and research-focused faculty, our work examines the possibility that PoTs, embedded within disciplinary departments with their research-focused colleagues, can act as departmental change agents who may influence the

teaching and learning conceptions and practices of other faculty members. If true, it may be beneficial for institutions who aim to promote equitable student success to hire similar teaching-focused faculty.

Theoretical frameworks

Teaching and learning theories

Undergraduate education has been experiencing a paradigm shift in the past few decades from a focus on the role of the instructor in the classroom to the role of the students (Barr & Tagg, 1995; McKeachie, 1991). Correspondingly, research on learning has expanded from teacher-centered instruction (Bransford et al., 2000) to considering students' needs and culture (National Academies of Sciences, Engineering, and Medicine, 2018) as well as power and privilege within educational contexts (Esmonde & Booker, 2017). While the students' role has been re-emphasized, the role that faculty play to facilitate the student learning process is still key as are their teaching and learning conceptions and the corresponding practices they implement that shape the student learning environment. Classically, faculty conceptions of teaching and learning are defined in a hierarchical scale beginning at limited conceptions, followed by intermediate, and, finally, complete conceptions (Prosser & Trigwell, 1999). This can result in instructional practices that range from traditional lecture to student-centered pedagogies that leverage collaboration, student agency in the learning process, and student-instructor interactions, all of which fall under the umbrella of "active learning" (Apkarian et al., 2021; Auerbach & Andrews, 2018; Ballen et al., 2017; Lombardi et al., 2021), where "undergraduate learners should be active agents during instruction and where the social construction of meaning plays an important role for many learners, above and beyond their individual cognitive construction of knowledge" (Lombardi et al., 2021). By integrating these two frameworks, we hypothesize that as faculty move towards more complete conceptions of teaching and learning, they also move from traditional, instructor-centered practices to implementing student-centered ones, ultimately resulting in the construction of student-centered learning environments, as shown in Fig. 1.

Limited conceptions + traditional instructor-centered learning environment

Instructors in higher education typically do not receive training to teach (Felder & Brent, 2016), and their teaching conceptions and practices often mirror those of their own instructors from when they were students (Adams

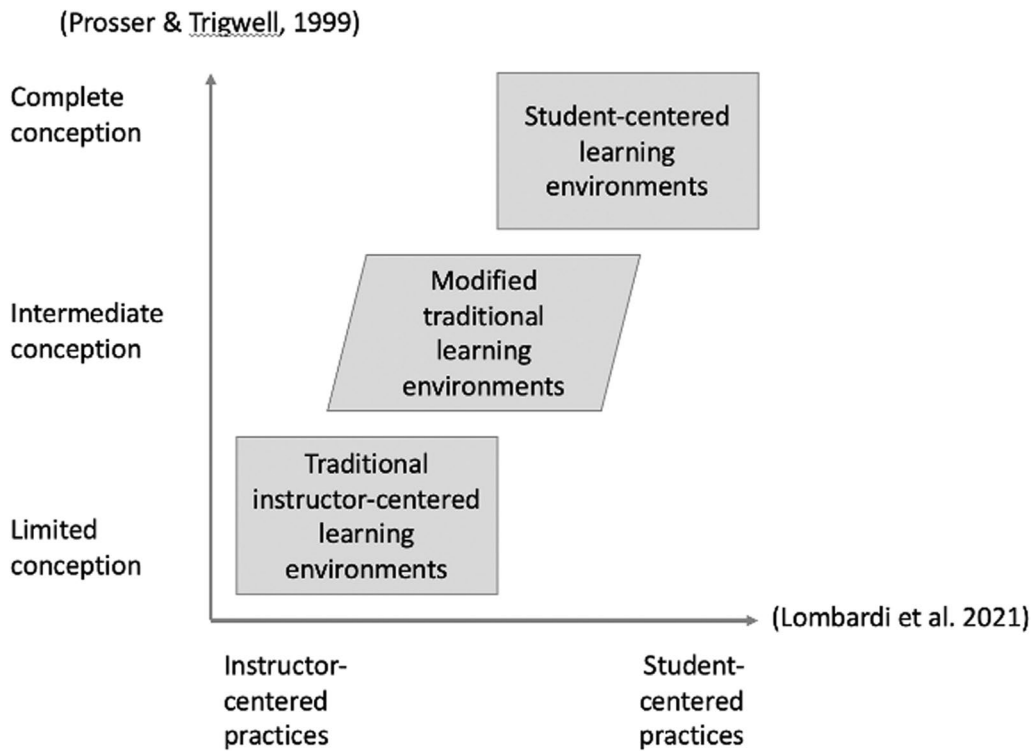

Fig. 1 Relationship between an individual's conceptions of teaching and learning (limited, intermediate, complete) and their instructional practices (instructor-centered practices versus student-centered practices). These conceptions and practices can result in the construction of traditional instructor-centered learning environments, modified traditional learning environments, or student-centered learning environments

& Felder, 2008; Sroka, 2015). Teaching as one was taught, which typically is synonymous with lecturing, without concomitant reflection often leads to conceptions of teaching that are considered "limited," where the definition of teaching stops with the instructor (Prosser & Trigwell, 1999). Corresponding conceptions of student learning typically center on accumulating facts and concepts to satisfy the demands of course assessments (Prosser & Trigwell, 1999). With a limited conception of teaching and learning, instructors focus on their own structure of knowledge and see their role as transmitting information without necessarily helping students understand how the components of information are related or whether they are based on students' prior knowledge (Smith et al., 2005). Sensemaking of content material largely or exclusively occurs within the instructor's course preparation, and expert-organized information is then transmitted to students (Lombardi et al., 2021).

Intermediate conceptions + modified traditional learning environment

In this conception, instructors recognize that students play a role in the teaching and learning process, and the goal of teaching is to help students acquire the concepts and skills that experts in the field have already developed (Prosser & Trigwell, 1999). Student learning is often viewed as the acquisition of content knowledge, typically to satisfy certain personal goals or curiosity in addition to the demands of course assessments (Prosser & Trigwell, 1999). While there is a shift towards engaging students, instructors who hold this intermediate conception still view their own structure of knowledge as the main consideration in the teaching and learning process (Prosser & Trigwell, 1999). Therefore, sensemaking of content material still largely or exclusively occurs within the faculty's preparation prior to class (Lombardi et al., 2021). Instead of information being simply transmitted, efforts are made to bring students to the expert-organized information to facilitate their acquisition of knowledge and skills (Prosser & Trigwell, 1999).

Complete conceptions + student-centered learning environment

Instructors with complete conceptions of teaching focus on their students' worldviews and changing understanding of the subject matter rather than their own knowledge of the field as experts. They see their role as creating a learning environment, where students are supported in developing their own conceptual understanding in terms of further elaboration and extension of existing knowledge (Prosser & Trigwell, 1999). Correspondingly, these instructors typically hold conceptions of student learning that focus on conceptual development and change through active construction of one's own knowledge (Prosser & Trigwell, 1999). In the learning environment, students are viewed as their own agents in making sense of disciplinary knowledge through engagement with data and scientific models, as well as considering their prior experiences in the learning process (Lombardi et al., 2021). Ultimately, this is reflected in teaching practices and policies that provide students with the autonomy to control their learning in collaboration with their instructor and peers (Cho et al., 2021; Haak et al., 2011; Manduca et al., 2017). Tables 1 and 2 illustrate the characteristics of different levels of conceptions of teaching and learning (limited, intermediate, complete) and corresponding example quotations, as well as present two types of instructional practices (instructor-centered and student-centered) and relevant quotes (the example quotations are taken from the interview data collected for this study).

Methods

Using the case of one STEM department at a research-intensive, minority-serving university located in the western United States, we explored faculty conceptions of teaching and learning, and uncovered how these conceptions manifested in terms of the faculty members' course policies and practices. We utilized qualitative methods and drew information from two data sources, which included semi-structured interviews with faculty and their syllabi. The goal of using both data sources was to get a deeper understanding of faculty conceptions and beliefs and how those helped shape their instructional practices. In addition, methodological triangulation—using multiple methods in one study—helped us ensure the validity of our findings (Guion, 2011).

First, we conducted ten semi-structured interviews: five with Professors of Teaching and five with Research Professors. Out of ten participants, four were at the Full Professor rank, four—Associate Professors, one—Assistant Professor, and one—Distinguished Professor; five participants were male and five—female. The interview protocol was created while reviewing the relevant literature (Calkins et al., 2012; Light & Calkins, 2008; Prosser & Trigwell, 1999) and included a number of questions that helped us capture the faculty's teaching and learning conceptions and self-reported instructional practices. In addition, we included critical incident questions—reflective questions that are designed to draw from the most memorable past moments that help understand one's future behavior—which allowed us to better comprehend what influenced faculty conceptions and practices over time. Grounding our interview approaches and protocol in the existing literature helped us ensure the data credibility (Shenton, 2004). We used a purposeful sampling

Table 1 Conceptions of teaching and learning

Conception level	Definitions	Example quotations
Limited	Teaching is defined as transmitting instructor's knowledge (expert-organized information) to students (Smith et al., 2005) Learning is defined as accumulating facts to satisfy the demands of course assessments (Prosser & Trigwell, 1999)	"The concepts themselves are so hard that there's no intuition at first. The intuition has to be fostered and you have to show the examples, you have to walk through the examples first before you can talk about anything at all. So, you definitely start from a blank slate. So, you have to create something there. And that means there's more lecturing involved, more direct conveying of information." "Learning is when I give students what they need to learn—the material, whether that's telling them the information or telling them what kind of problems they need to be able to solve or where to get information."
Intermediate	Teaching is helping students acquire instructor's (expert's) knowledge and develop skills (Prosser & Trigwell, 1999) Learning is acquiring content knowledge and developing skills to satisfy certain personal goals or curiosity in addition to the demands of course assessments (Prosser & Trigwell, 1999)	"Teaching is not just having them recite the material. Anyone can read it from the book. My role is to help them understand it and be able to use it. And also give them strategies for the effective mastery of the material. If I don't explain, if I don't help them learn, they will not do it." "Learning is being able to use knowledge. It's not sufficient to just know facts, you have to be able to put it into practice. For the lab, that's very straightforward—can you operate the instrument? Can you draw conclusions from your data?"
Complete	Teaching focuses on students' worldviews and changing understanding of the subject matter (Prosser & Trigwell, 1999) Learning focuses on conceptual development and change through active construction of one's own knowledge (Prosser & Trigwell, 1999)	"It's being able to set up an environment where you're getting the students to go from basic recall and remembering and being able to list out facts to getting them to the point when they're categorizing, and then finally analyzing and creating stuff. When you're learning you're able to get to the point where you're doing those higher order things." "Learning is being able to take knowledge in and to make it your own… To me, anything that you learn, whatever it is, it's as if you're learning another language, as if you're learning another way of thinking, and so, learning is gaining that ability to think under the constructs of whatever that particular discipline is."

Table 2 Instructional practices

Practices	Definitions/examples	Example quotations
Instructor-centered	Instructors deliver information (course content) without necessarily helping students understand how the components of information are related or whether they are based on students' prior knowledge (Smith et al., 2005) E.g., lectures, traditional assessment practices (few big exams/tests)	"So, every time there is a lot of repetition and a lot of explaining, a lot of examples, a lot of analogies…. So, there's a lot of lecturing in that course." "Teaching for me is really conveying things that I have accumulated over my career. During my career, there were components that have helped me a lot and made me an expert in a certain discipline. So, I try to somehow communicate important elements of that to younger people. So, it's really the conveying of information and, therefore, through the information, the associated skills that come with that, right? Well, nowadays of course a lot of active learning is taking over, but there's still a lot of information that has to be somehow introduced before that."
Student-centered	Instructors create a learning environment where students are supported in developing their own conceptual understanding in terms of extension of existing knowledge and where students have the autonomy to control their learning in collaboration with their instructor and peers (Prosser & Trigwell, 1999) E.g., active learning practices (pair/group work, student presentations, collaboration), non-traditional assessment practices	"There is educational research showing that doing something else and then coming back to the same topic is effective in helping to consolidate knowledge in one's memory. Basically, making students discuss and explain the material to each other—that's very effective. That's especially obvious in office hours when you sit with them, and they solve problems in front of you and talk. There is this aha moment for students who didn't get it. Then after talking to their classmates, they finally get it." "Everything else is centered around group work, they're using the monitor, they're using the white boards, sometimes I put up a Google Doc and have all 100 people in the room start writing into the Google Doc. I actually find it really interesting because they come up with some stuff like wow, I didn't think of that. I actually enjoy teaching like that because it's as if I'm not controlling the class anymore the same way that I would if I was giving a narrative lecture."

strategy, that is, we recruited participants who would be able to provide in-depth information about the studied phenomenon (Crossman, 2020). The interviews lasted up to 60 min and participants received gift cards for their time. Interview data were audio recorded, professionally transcribed verbatim, and checked for accuracy by the research team.

The data were then organized and coded by three members of the research team using Atlas.ti software. The coding process included creating initial codes, revising and combining codes, identifying recurring themes and their relations to one another, and searching for patterns across different interviews. While constructing the codebook, we began with deductive coding with a set of a priori codes derived from previous literature and theory that helped us capture faculty conceptions of teaching and learning and self-reported instructional practices. Then, the process of inductive coding, with codes derived from the data, helped us look at the variations of those conceptions and practices among the faculty members. The codebook underwent multiple rounds of revision before being applied to all of the transcripts. To ensure rigor and inter-rater reliability, consensus coding was used (Richards & Hemphill, 2017) with a number of interviews coded by 2–3 researchers, and any discrepancies in coding discussed and reconciled. The codebook included such categories as teaching and learning philosophies and methods, environmental influences on attitudes and conceptions, faculty interactions, as well as categories related to fixed versus growth mindset and professional development related to teaching and pedagogy. In the second round of analysis, two researchers compared findings from the interviews with PoTs and RPs.

Second, we obtained one syllabus from each of the interviewed faculty members to examine how they might enact their conceptions in practice and we used these syllabi as a proxy for the faculty's instructional environments. We specifically requested a syllabus from a lower division, large-enrollment course, as these are traditionally known to serve as barriers to STEM student success (Seymour et al., 2019). It is important

to note that the given department did not offer syllabus templates or have specific requirements to the course syllabi, so faculty members structured their syllabi in the way that they saw fit for their courses. For the syllabus analysis, we used a scale (rubric) that was developed to measure learner-centeredness in course syllabi by Cullen and Harris (2009) (included in an Additional file 1). The analysis rubric was divided into three categories: community (fostering the sense of community and collaboration among students), power/control (creating an environment where control is shared by instructors and students), and evaluation/assessment (the amount and type of feedback provided to students). To ensure inter-rater reliability and data confirmability, each syllabus was coded and evaluated independently and iteratively by two researchers to compare and discuss coding interpretations (Anfara et al., 2002; Shenton, 2004). When coding appeared to be ambiguous, the discrepancies were discussed in regular research team meetings until consensus was reached.

Positionality statement

To increase the transparency and trustworthiness of our work (Holmes, 2020), we include a positionality statement. We acknowledge that our own experiences as education researchers (all authors) and members of the Professor of Teaching series (BKS, SML, NTB) may have influenced the way we collected and analyzed the data (Rowe, 2014). VR is a postdoctoral scholar in an education research center with a PhD in education. LS is a graduate student in an education PhD program. BKS and SML are both tenured teaching faculty in biology and primarily work in discipline-based education research. NTB is a tenured teaching faculty in engineering and exclusively conducts discipline-based education research. We all work in the context of a research-intensive institution. Together we use both our professional experiences and education research training to critically evaluate the literature and interpretation of our data. We do this to provide authentic findings with measures to reduce biases.

Results

The results of this study are presented in three sections which correspond with the three research questions—the first focusing on conceptions and practices of PoTs, the second focusing on conceptions and practices of RPs, and, finally, the third synthesizing the results from both sample populations to address research question 3. Table 3 presents the main themes from the interview data for research question 1 (RQ1) and research question 2 (RQ2). Table 4 presents the demographic characteristics of each study participant and summarizes the analysis of their interview and syllabus data.

Research question 1: what are Professors' of Teaching conceptions of teaching and learning and how do these conceptions inform the development of their instructional environments?

Interview data

Themes that emerged from the interviews with Professors of Teaching include the following: (A) PoTs' conceptions of teaching and learning mostly fall between intermediate and complete levels, (B) PoTs' conceptions translate into the implementation of student-centered instructional practices and the creation of student-centered learning environments, and (C) PoTs believe that beyond constructing a student-centered environment, instructors must play a supporting role both inside and outside the classroom. The analysis summary for each study participant can be seen in Table 4.

Theme A: PoTs' conceptions of teaching and learning mostly fall between intermediate and complete levels. The interviewed PoTs reported teaching large-enrollment courses ranging in size (from 200 to 600

Table 3 Themes that emerged from the interview data

RQ1: What are Professors' of Teaching conceptions of teaching and learning and how do these conceptions inform the development of their instructional environments?	RQ2: What are Research Professors' conceptions of teaching and learning and how do these conceptions inform the development of their instructional environments?
Theme A: PoTs' conceptions of teaching and learning mostly fall between intermediate and complete levels	Theme A: RPs' conceptions of teaching and learning mostly fall into the intermediate level
Theme B: PoTs' conceptions translate into the implementation of student-centered instructional practices and the creation of student-centered learning environments	Theme B: RPs conceptions translate into the implementation of a mix of instructor-centered and student-centered instructional practices and the creation of modified traditional learning environments
Theme C: PoTs believe that beyond constructing a student-centered environment, instructors must play a supporting role both inside and outside the classroom	

RQ3 is answered as a synthesis of RQ1 and RQ2

Table 4 Faculty conceptions of teaching and learning, syllabus scores, and teaching practices

Faculty position	Rank	Sex M/F	Conception level (limited, intermediate, complete)	Syllabus score (max 48)	Practices (instructor-centered, student-centered)
PoT 1	Full Professor	F	Intermediate/complete	21	Student-centered
PoT 2	Associate Professor	F	Intermediate	31	Both instructor/centered and student-centered
PoT 3	Associate Professor	M	Intermediate/complete	43	Student-centered
PoT 4	Full Professor	F	Intermediate/complete	23	Student-centered
PoT 5	Associate Professor	F	Intermediate/complete	44	Student-centered
RP 1	Full Professor	M	Intermediate	30	Both instructor/centered and student-centered
RP 2	Associate Professor	M	Limited/intermediate	15	Both instructor/centered and student-centered
RP 3	Assistant Professor	F	Intermediate	18	Both instructor/centered and student-centered
RP4	Full Professor	M	Intermediate	17	Student-centered
RP5	Distinguished Professor	M	Limited/intermediate	25	Both instructor/centered and student-centered

students) and level (first-year students, seniors, honors students). The interview data revealed that PoTs' conceptions of teaching and learning mostly fell between intermediate and complete levels, which translated into classroom practices that minimized lecturing and instead included a number of active learning pedagogies. In general, PoTs were striving to motivate their students to move away from memorizing and simply "spitting out facts" and to instead focus on categorizing, analyzing, and reflecting on the studied material. In addition, they stressed the importance of developing skills and knowledge (a hallmark of intermediate conceptions), as well as the significance of students being responsible for their own learning instead of simply following directions (complete conception). This is how one faculty member described their conception of learning, which corresponds to the complete level:

> *Learning is being able to take knowledge in and make it your own, being able to interpret and understand it. To me, anything that you learn, whatever it is, it's as if you're learning another language, as if you're learning another way of thinking, and so, learning is gaining that ability to think under the constructs of whatever that particular discipline is.*

Very few PoTs stressed the transition of knowledge in their role as instructors (limited conception) and instead highlighted the need to set up a structured learning environment and provide students with resources (i.e., learning materials and academic support structures). In line with the previously mentioned importance of acquiring knowledge, PoTs specifically said that it was key for students to be able to apply that knowledge to solve problems in novel scenarios, and ultimately, in the real world (complete conception). One PoT discussed how this learning may require trial and error:

> *You'd memorize a bunch of things, but how useful are they? Yes, there are things you have to memorize, but then after that you have to apply them. You have to use them. You're never going to get better if you don't apply them to new situations and you're not going to get better if you don't mess it up and have people call you out when you mess it up, right?*

Another PoT echoed this opinion in the context of classroom assessment:

> *Learning is being able to use knowledge. It's not sufficient to just know facts, you have to be able to put them into practice. For the lab, that's very straightforward, "Can you operate the instrument? Can you draw conclusions from your data?" In the lecture it's, "Do you know the terminology and the vocabulary, and can you explain the phenomenon?" but then can you apply them to situations that aren't exactly what we talked about in lecture. Students who have learned the material can do that stuff.*

The discussion of skill development and application often touched on the importance of critical thinking skills that can be leveraged outside of the classroom. According to the interview participants, critical thinking skills are fundamental for students' future career, research, and everyday life. Below is how one of the PoTs stressed the necessity for students to develop critical thinking:

> *I think if you have critical thinking skills, you can learn anything you want. If you don't have those, then you're going to get tripped up all over the place and you're going to put in a lot more work than what you really need to put in … and it's just kind of these basic critical thinking skills that they never developed, they were never taught, they never got somehow.*

Although an emphasis on skill development often falls under the intermediate level of conceptions, because most PoTs talked about skill transferability to scenarios outside of the classroom, it denotes a complete conception. Another PoT also took it one step further and defined successful learning as moving from skill application (intermediate conception) to assuming more responsibility and making knowledge "your own" or enabling students to create new knowledge (complete conception):

> *I think creating a situation where the students are able to turn around and have the freedom to apply things is important. Because at that point they're no longer following directions, they're actually responsible for what they're doing. It is teaching techniques and skills versus teaching how to think. The space has to be there for them to take it to that next level, for it to become their own, for them to have done something with all of this stuff. Instead of answering question by question, they actually take something and create something on their own with it. That's effective learning to me is when you've gotten them to the point where they're able to make something their own in some way.*

One of the PoTs further elaborated on students demonstrating a "higher level of thinking" which included applying acquired skills into practice (while trying to solve a problem, for example), explaining their solutions and decisions, identifying one's gaps in knowledge, recognizing what additional evidence they need to collect to solve the problem, and finding that information that will help them to better support their arguments or solutions.

Theme B: PoTs' conceptions translate into the implementation of student-centered instructional practices and the creation of student-centered learning environments. Professors of Teaching consistently emphasized the importance of supporting and guiding students ("nudging them in the right direction") through their instructional practices, helping them to move from memorizing of facts to analyzing and interpreting the presented material (intermediate conceptions), as well as encouraging students to think critically and establish connections (complete conceptions). Below is how one of the PoTs described a way that learning should be fostered in the classroom:

> *Well, learning doesn't have anything to do with me lecturing, that's for sure. Learning has to do with being able to set up an environment where you're getting the students to go from basic recall and remembering and being able to list out facts to getting them to the point when they're categorizing, and then finally analyzing and creating stuff.*

Aligning with this perspective, when asked how they viewed their role, most PoTs called themselves guides or facilitators and not simply deliverers of knowledge, aiming to increase student engagement and creating a more dynamic classroom experience:

> *I see my role as a facilitator. I don't like to lecture for long periods of time. I mean, I can do it. I just don't think it's effective. You can watch people fading out, looking on their phones… they're not engaged. Give them maybe a representative sample of how they're going to need to apply the knowledge in the future, give them problems that are relevant to their future career, give them labs that make them think about that kind of thing.*

Aligned with this desire to implement active learning elements in their classes, PoTs described "good" learning strategies as those that enabled students to learn independently—being able to apply the previously received knowledge to other problems and finding new solutions. According to the PoTs, it is important to let students explore and create their own knowledge based on what they had already learned, even if it requires a trial-and-error approach:

> *As a part of active learning, in the lab, I give them procedures that are not a full recipe that they just follow the steps. There's stuff left out, there are decisions that they have to make. They're going to learn how to use the instrument because either they're going to figure it out, read the literature, and figure out the correct answers, or they're going to try it and do it incorrectly and it's not going to work, and they're going to learn that that's not the right way to do it.*

This PoT felt that enabling their students to make their own decisions, possibly resulting in a failure, was a more effective learning experience as opposed to providing ready solutions directly to the students.

Theme C: PoTs believe that beyond constructing a student-centered environment, instructors must play a supporting role both inside and outside the classroom. During the interviews, Professors of Teaching consistently stressed the importance of supporting students throughout their learning process both in class and beyond classroom instruction. To build a student-centered learning experience, they emphasized the instructor's role in supporting students and creating an environment where students can thrive academically. One of the PoTs described the importance of continuously nurturing students:

I do a lot of things. I teach them concepts, I show them how to work problems, I show them how to do well in my class. I'm super nurturing just by nature. … I don't go up there and say, "Okay, this is what it is and too bad if you don't get it." That would be anti-nurturing. I try to help them along all throughout the whole year.

Furthermore, PoTs paid particular attention to the importance of making the course content relevant to students' future career goals and aspirations to motivate and encourage their learning. Below is how one of the PoTs described their role:

I think student motivation is really important. If they're not motivated to learn, they're going to have a hard time trying to make meaning of things and go beyond just memorization. I try to point out to them why they should care about the class even if they don't think they should care about the class. If you're going to get a job as a [discipline-specific industry position], you're going to use these instruments and these concepts. If you're going to go to graduate school, you still may have to use the same instrument. They haven't always thought about it that way, but I think I can convince most of them that the material we're covering is going to be relevant eventually.

Another PoT said that they would like students to experience the "Wow, I really know how to do this now!" feeling when they are learning. To achieve that, on the first day of class, this professor demonstrates to her students what they should be able to do upon completion of the course while highlighting the most exciting segments of the material that they are likely to find most relevant.

In addition, other PoTs stressed the necessity of helping students develop "good study habits", which they defined as being open to trying something new, learning from one's mistakes, and being willing to step outside of one's comfort zone. It is important to mention that throughout these processes, PoTs viewed themselves as guides who help students navigate the material and support them through their learning. While doing so, one professor noted that they specifically ask students beforehand to voice their expectations of the class, as well as future graduate school and career aspirations, so that these goals can be taken into consideration throughout the course.

Syllabi data

To examine how instructor conceptions of teaching and learning translate into classroom practices and whether there was an alignment with their self-reported practices, we conducted a syllabus analysis, leveraging a validated rubric that measures the degree of learner-centeredness of this ubiquitous course artifact (Cullen & Harris, 2009; Eslami et al., 2022). Specifically, the rubric examines how a syllabus addresses the following course features: community, power and control, and evaluation and assessment. The maximum rubric score was 48 with higher scores indicating a more student-centered learning environment (Table 4).

As a whole, PoTs' syllabi scores ranged from 21 to 44, which indicates a higher level of learner-centeredness of their courses as compared to their RP colleagues (Table 4). A hallmark of the PoTs' syllabi that stood out was the way in which they were designed and structured. Four out of five PoTs created a syllabus of more than 10 (up to 23) pages with the fifth having mainly outlined basic class requirements and assessment procedures in a much shorter syllabus [previous work has shown that length of syllabi correlates with an increased degree of learner-centeredness (Richmond et al., 2019)]. Two professors also made an effort to make their syllabi look more user-friendly and attractive by utilizing different colors, graphics, various text arrangements, and fonts.

Community The community feature of the syllabus rubric examines if/how the sense of community is being fostered in the classroom, whether an instructor is trying to create a sense of relevance to the learning environment, and whether an instructor is accessible and committed to student learning (Cullen & Harris, 2009). All PoTs provided their email and room number for office hours, with some encouraging interaction with students by explicitly inviting them to attend office hours or reach out for help. Most of the PoTs were also very transparent as to why they may be temporarily unavailable or may not respond to emails immediately, for example, mentioning the large class size. Below is one example of such explanation:

I am available by email weekdays, and answer > 95% of emails from students. Sometimes the volume of emails is so high that I can't answer everyone, and often, before a test, I will email the entire class about the FAQ's. Don't forget there is only one of me for 400 of you!

In the examined syllabi, collaboration among students was, for the most part, encouraged and in two cases was required for a number of assignments. PoTs frequently provided rationale for the given assignments as well as included tips for success along with learning goals and class requirements. Many of those tips went beyond just what students needed to do to succeed in class and included suggestions on how to develop more interest in the subject and the specific field of study more broadly.

Power and control The power and control feature of the syllabus rubric examines how power is shared between instructors and students and helps identify whether a student is seen as a partner in the teaching and learning process rather than a recipient of knowledge (Cullen & Harris, 2009). According to Eslami et al. (2022) whose study looked at the relationship between student-centered pedagogies and opportunity gaps (the difference in grades earned by minoritized and non-minoritized students), the power and control rubric factor was most correlated with the smaller opportunity gaps. Large enrollment sizes of the introductory classes taught by the faculty members in our sample seemed to contribute to a more passive student role described in the syllabi, equating to limited shared responsibility in terms of class presentations and new knowledge contribution. Only one Professor of Teaching made in-class presentations a requirement, which helped to emphasize the importance of student-generated knowledge. One syllabus had a section on the benefits of active learning, explaining why these practices are good for student learning and how they can maximize these benefits. Two of the syllabi also included *"What to expect from the instructors"* section. The instructor's role was coded at the most learner-centered ratings for most of the syllabi, which means that instructors left space for students' voice in developing class policies and assignment choice/due dates.

As for the resources suggested in the syllabus, all of the studied PoTs' syllabi mentioned required textbooks and lab guides as well as links and references to the outside resources and learning materials, the use of which was encouraged but not required. In addition, some of the syllabi suggested additional campus resources, such as tutoring, peer mentoring groups, the campus writing center, and others. Based on our analysis, only two PoTs' syllabi expected students to incorporate some independent investigation of resources to aid in their learning. One of them also provided space (via discussion board) for student questions to be posed and solved by the class community.

Evaluation and assessment This syllabus rubric feature examines assessment as ongoing formative feedback and as a summative determination of whether the learning outcomes were met (Cullen & Harris, 2009). From the PoTs' syllabi, student knowledge and performance assessment appeared to be mostly summative (midterms and final exams with some homework/lab assignments) with feedback provided on a case-by-case basis. Some PoTs reported having added open-ended questions to their tests to get a better grasp of students' thought processes and understanding of the subject; this change was reflected in two syllabi. Furthermore, the majority of the syllabi noted that the redoing of assignments was allowed, and sometimes encouraged. The focus in terms of how students earned grades was on the accumulation of points; however, the number of points was generally tied to student learning outcomes. Related to the assignment revisions, the ability to regain points was frequently offered.

All PoTs' syllabi included an academic integrity section that clearly explained what that meant and the consequences of failing to adhere to these standards. Two out of five syllabi also contained disability statements addressing potential learning differences among students and corresponding course opportunities; one had an additional section outlining student pregnancy and maternity exceptions. Overall, the PoTs syllabi emphasized learning outcomes and class policies that were more flexible to facilitate student learning.

Research question 2: what are Research Professors' conceptions of teaching and learning and how do these conceptions inform the development of their instructional environments?

Interview data

We next present the interview and syllabus analysis from instructors in the Research Professor track. Themes that emerged from the interviews with RPs include the following: (A) RPs' conceptions of teaching and learning mostly fall into the intermediate level, and (B) RPs conceptions translate into the implementation of a mix of instructor-centered and student-centered instructional practices and the creation of modified traditional learning environments (Table 4).

Theme A: RPs' conceptions of teaching and learning mostly fall into the intermediate level. The interviewed Research Professors reported teaching a wide range of courses with enrollments of 60 to 450 students at all levels, including introductory, advanced, and honors courses. Many professors taught courses that were part of a series and felt responsible for preparing students for the subsequent lecture or laboratory course. In terms of their conceptions of teaching and learning, the majority of the quotations from the interviews were coded between limited and intermediate with most of them falling into the intermediate level (we highlight limited conceptions in the vignettes in the discussion of theme B below). Very few RPs' quotations indicated complete conceptions.

Nearly all RPs valued teaching students to solve discipline-specific problems (intermediate conception). At times that value was motivated by the demands of the subsequent course for which their course served as a prerequisite. More specifically, they felt responsible for preparing students for more advanced courses and viewed their course as foundational. This reflects an intermediate conception, because the RPs did not consider students'

current worldviews when deciding on how to structure their courses. RPs further reported creating assessments and evaluating learning by seeing if students could apply knowledge and solve problems on their own. Students' independence in understanding the course materials is a hallmark of intermediate conception. Furthermore, RPs often said that the capacity to approach problems with confidence required contributions from the student that were outside of the instructor's capacity to influence. One RP explained their role as an instructor as follows:

> *You're [speaking of instructors generally] the one who's mediating the material and who's making sure that the material somehow arrives and translates into skills and knowledge retention, right? So that is your job. Although I would say that's partially your job because I think the student has also a real responsibility. I cannot be responsible for the student's attention alone.*

In addition, RPs spoke about the desire for students to appreciate and admire the given discipline and science more broadly. Attention to students' global understanding of the subject reflects an intermediate conception. It can also suggest that professors were concerned about how their courses impacted students' worldviews, which is a hallmark of complete conceptions. Many RPs stated that learning became easier when students enjoyed the subject and suggested that success in their course was contingent on a student appreciating and enjoying the learning process. They felt that this appreciation for the subject was something instructors could encourage, but only to a certain degree. Below is how one RP described their limits in influencing students in that respect:

> *I have rarely seen people who do very well in my class that hate the material. So, there's a clear correlation between people who actually like it and do well, right? So, if something piques your interest, you're much more likely to at some point become fairly good at it. So, enthusiasm for a certain topic is important and that's something that I try to foster, but I'm not always successful with everybody, of course.*

Despite the instructors' feeling that students must shoulder some of the burden to successfully learn the material, they did note a desire to support this process. For example, one RP stressed the importance of office hours and discussion sessions:

> *I can't cause somebody to learn it. It's like a personal thing, you have to want to learn and put in the time and the effort. I can't just give you information and tell you how that makes sense. You have to be able to analyze and integrate it. And that comes through practice and through them being able to ask a question back. And that's why we have all these help sessions too, so that they can actually practice and see where it's not working and then can work through that specific misunderstanding by themselves.*

In this rare case, an RP explained the teaching and learning practices using a complete conception. They understand that learning occurs when individuals experience a shift in thinking/perspective. In addition, some RPs mentioned using active learning pedagogies to support student learning and the importance of training students to solve problems and acquire skills. However, only one professor explicitly spoke about the need for students to demonstrate a direct transfer of knowledge to the real-world scenarios and few professors mentioned learning that may potentially cause a shift in students' worldviews.

Theme B: RPs conceptions translate into the implementation of a mix of instructor-centered and student-centered instructional practices and the creation of modified traditional learning environments. Although most Research Professors understood the value of active learning, their teaching and learning conceptions did not always translate into the practice of generating student-centered learning environments. Active learning was in many ways a "buzzword" in the interviews with RPs. By "buzzword", we mean that all RPs appeared to consider active learning to be current, important, and valued in higher education and STEM teaching and learning, yet there were also consistent reservations about heavily leveraging it as opposed to traditional lecture. In one instance, an RP explained that their students requested active learning and even spoke of other professors, often PoTs, who had leveraged active learning in productive ways. Upon hearing feedback from their students, this RP adjusted their practice saying, *"I know it is an increasing trend that students expect active learning elements, they expect not just the lecture but active participation in all of the classrooms."* In another instance, active learning was brought up when RPs reported attending professional development activities, discussing teaching strategies with PoTs, and adjusting their practices to meet requirements to teach in new classroom spaces specifically designed for active learning.

Overall, the RPs who reported using active learning did so to enable collaborative problem-solving sessions. For example, one professor described the following:

> *Essentially, I make them think about a certain problem or try to solve it and then discuss with each other and then we discuss it together. That's some maybe 20% of the class. It's not flipped, not com-*

pletely active learning, so there is just, maybe some elements of it.

The decision to replace part of their lecture time with active learning practices was often to assist academically struggling students. Many RPs suggested that struggling students were able to understand the topics better when they were given time to think and discuss during class time. For example, one RP reported:

So, I think active learning is good for making things a little bit more accessible overall, I guess. Bringing the next layer of people who may have not been able to digest material and they can do it through activities, can do it with their peers. So, I guess it plays an important role. It's my job to make it maybe not so hard, so that everybody can actually enter that domain and appreciate it.

This RP implemented active learning but did not appear to fully buy-in to its value. This became even more obvious through discussions with an RP who we refer to as Jaime. While most RPs fell into intermediate level, Jaime, conveyed a complete conception when defining and explaining his perspectives of the learning process. According to Jaime, learning is the process of figuring out new information on one's own, contextualizing this new knowledge with other facts and internalizing the information in a way that changes one's current state of mind. Jaime explained learning to be: *"the process of internalizing the material and giving meaning to that material, so that [it] becomes a part of your own makeup."* This is considered a complete conception, because Jaime highlighted the importance of changing one's perceptions while learning, not simply acquiring new skills or retaining new information. In contrast, Jaime was also categorized as having a limited conception when defining teaching and discussing their instructor-centered teaching practices. In regard to teaching, this professor said:

Teaching for me is really conveying things that I have accumulated…during my career… components that have helped me a lot and made me an expert in a certain discipline. So, I try to somehow communicate important elements of that to younger people. So, it's really the conveying of information and therefore through the information, the associated skills that come with that.

While elaborating on the process of learning, Jaime described the importance of internalizing knowledge which is a necessary step to becoming an expert; this view corresponds to the complete conception. When speaking about teaching, Jaime described the responsibility of an expert to transfer knowledge to students who have not experienced or accumulated the same knowledge, which indicates the limited conception. Jaime's current teaching design was guided by his past experiences, and he prioritized passing on the disciplinary knowledge he obtained to the next generation of rising experts. Transferring knowledge directly from expert to novice does not contribute to a learning environment that explores the students' current worldviews or their development of personal conceptions. Jaime's limited conception was further evident when he explained the importance of lecturing:

The concepts themselves are so hard that there's no intuition at first. The intuition has to be fostered and you have to show the examples, you have to walk through the examples first before you can talk about anything at all. So, you definitely start from a blank slate. So, you have to create something there. And that means there's more lecturing involved, more direct conveying of information.

By describing the learner as a blank slate, Jaime was less concerned with what the students currently know and have to bring to the table, and primarily concerned with imparting what they need to know.

Another professor, who we call Riley, also simultaneously demonstrated both limited and complete conceptions of teaching and learning. Riley often spoke about how their course was situated within the department and how student learning in other courses was connected. It is important to note that Riley holds several administrative roles beyond the usual teaching and research duties. These assigned roles provide opportunities for Riley to see how other professors teach and how learning in one course is connected to success in another. In particular, Riley stressed the importance of students mastering the content of the course: *"There is a curriculum, and my goal is so that by the end of the quarter they [students] understand the material enough so that they can move on to more complicated classes"* (limited conception).

When asked about the process of learning, which Riley equated to the integration of new knowledge with existing knowledge, Riley explained that some students struggled to learn, because they failed to see how the course material connected to other courses and to real world concepts (complete conception):

They just cannot connect the materials…it's not clear to them why they have to know this. Some topics are interesting to them, other students say, "Okay, why do I need to know crystal structures? I will never touch crystals in my life, maybe." They don't see the importance of what they need to know for their future.

Riley was describing the process of learning that required connections beyond the classroom, including a personal connection between the material and the learner's future aspirations. At the same time, when Riley talked about their priorities as an instructor, they described targeted learning outcomes essential to succeed in advanced courses. The two ideas, learning primarily to advance in the program and learning to connect to the real world, seem to be disjointed. Perhaps this is due to how this professor viewed the ownership of the tasks. Riley took the ownership of preparing students for subsequent courses but seemed to suggest that students must take the ownership of understanding how the material connects to their lives outside of the classroom. When a classroom is student-centered and a professor has a complete conception of teaching and learning, the student and instructor take on a collaborative partnership to ensure that the learning experience includes evolving perspectives and shifts in worldviews.

Syllabi data

As a whole, RPs' syllabi were less student-centered relative to those of their PoT colleagues, ranging from 15 to 30 points (Table 4). This was observed throughout each of the three rubric features.

Community Three out of five RPs' syllabi included instructors' email addresses and prescribed office hours located in the professor's office but there was no encouragement for students to attend these sessions. In their syllabi, RPs never discouraged direct communication, but opportunities to meet with them were limited or often not mentioned. Thus, all RPs' syllabi displayed limited accessibility to their students.

Similarly to the accessibility of the instructor, such information as learning outcomes and explanations for prescribed assignments was missing in many cases; most RPs failed to demonstrate how the assignments and class activities would help students to arrive at the projected learning outcomes. There were two Research Professors, however, who displayed a higher level of student-centered learning rationales in their syllabi. One RP explained how various assignments would help students understand the studied subject and its position in the field more broadly. Another RP listed learning outcomes with each assignment. None of the RPs' syllabi were considered fully student-centered, because their learning rationales did not relate to policies and procedures that could foster more productive learning.

Furthermore, four out of five RPs did not mention collaboration in their syllabi. One RP included collaboration in a section titled *"How to succeed in this course"* where it was suggested that collaboration was a good way for students to self-assess their level of understanding by comparing themselves to others and asking for or offering help as needed to learn the concepts on a deeper level.

Power and control Three out of five RPs displayed no shared power with students including providing no accommodations or flexibility within the policies and practices outlined in their syllabi. Success in the course involved attending all prescribed lectures, discussion sections, and limited office hours. The tone of these syllabi suggested that students' success was contingent on doing exactly what the professor outlined. Such syllabi lacked references to student input or contribution in forming course policies. The remaining two RPs did provide flexibility through their syllabi with one offering an optional final exam, which enabled student agency, and another including a flexible grading scale and offering extra credit and points for class participation. Both syllabi, however, did not allow for input from students, a key feature of a student-centered course.

RPs frequently dedicated significant space in the syllabus to course schedules which included due dates, textbook readings, and homework assignments. One stated in the syllabus, *"please review the detailed day-by-day schedule."* Two other RPs overused commanding language when addressing students. For example, one stated, *"each student will fill out a… template that requires you to evaluate several aspects of the papers."* One professor did share control over knowledge acquisition with students by adding some encouragement for them to go beyond the minimal required content and search information outside of class. In regard to the overall focus of the syllabi, two RPs only covered course policies; two other RPs focused on course policies and procedures with some reference to content and learning outcomes; and one RP provided students' learning outcomes and goals with little reference to course policies.

Evaluation and assessment Most of the RPs displayed quite high levels of student-centered evaluation practices in their syllabi. One RP assigned diverse forms of assessments, including homework assignments and low-stakes quizzes that accounted for a significant portion of students' final grade as opposed to relying solely on high-stakes exams. Another RP included various checks for understanding and participation opportunities during class time. One more RP stated that participation in class and discussion sections accounted for 40% of students' overall course grade. Although these three professors described diverse forms of evaluation, none of them explicitly mentioned student presentations or group-work as required assessment elements. The two remaining RPs only included quizzes and exams as the forms of assessment.

References to outside resources were also diverse within the RP sample. One RP required students to attend a commercial/private/non-university research lab with an explanation for why this experience was important for their learning generally, not just for succeeding in the course. Another RP dedicated considerable space on their syllabus explaining optional resources including how to access those, the type of support offered, and the importance of those resources. Two other RPs suggested using optional textbooks or tutoring to help students learn but did not require students to use those resources. One RP simply listed the required text.

Finally, two RPs did not address opportunities for feedback in their syllabus. The other three professors allowed students to see copies of their graded assignments with a formal procedure to correct any grading errors. None of the RPs mentioned opportunities to discuss students' assignments or general progress in the course. Regrading was offered to "correct serious errors" and submitting such a request would result in "regarding the entire exam". Some professors even warned that regrading might result in a lower grade, which might have discouraged some students from requesting a regrade. None of the RPs offered low stakes feedback in the form of non-graded assignments or assessments. Most RPs also emphasized the accumulation of points disassociated from learning outcomes.

Research question 3: if teaching and learning conceptions and instructional environments vary between PoTs and RPs, are PoTs influencing their RP colleagues in these areas?

As PoTs tended to have more complete conceptions of teaching and learning than their RP colleagues as a whole (Table 4), we were curious as to whether PoTs influenced RPs in this regard. When RPs were asked about mentors and colleagues who influenced their teaching, they mentioned past mentors from their PhD programs, pedagogy-related courses/seminars, and PoTs. Nearly all RPs mentioned casual interactions with PoTs related to teaching, including a few Research Professors who reached out to one particular Professor of Teaching for course materials and advice on teaching methods and others who worked directly with PoTs on common curriculum and assessments. All RPs spoke positively about their colleagues and departmental culture while referencing PoTs as experts in teaching. One RP stated:

> *I also chat with the Professors of Teaching in the department who are an amazing resource and regularly email them when weird things come up. They see so many students, they've seen everything, I think. And so, they're wonderful resources both from the logistics of teaching and interacting with so many people. And also, in terms of pedagogy as well.*

This quote suggests that some RPs felt comfortable reaching out to PoTs for advice. They thought of PoTs as resources for immediate support as they faced challenges in teaching. This RP reached out to PoTs with questions, because they saw them as experienced and able to give advice on a variety of different courses and class environments.

RPs' praise and respect towards PoTs were not constrained to surface level references, rather they often gave specific reasons for believing that PoTs were experts in teaching. When one RP was asked about their interactions with PoTs in their department, they explained:

> *So, he [the PoT] is in charge of the curriculum more or less, and he's organizing the common final. So, he has certain ideas about how to approach or how to do that, that's rooted in some of his own research. How students learn how to improve themselves. So, he really thinks very deeply about those things. And so, some of those things find their way into the courses. And the instructors who teach coordinate with him, so this cross fertilization is happening there.*

In this quote the RP is not only supportive of the PoT's curation of the curriculum and exams, but they see the merit to how this PoT thinks about teaching and learning, stressing the connection to the PoTs' own education-focused research and the empirical data used to support teaching-related decisions.

The PoTs also confirmed having teaching-related conversations with RPs. From their perspective, RPs mostly reached out to PoTs when they needed advice on specific activities that they were attempting to implement in their classes, particularly active learning pedagogies. These conversations happened sporadically and casually and only with those RPs who were interested in modifying and improving their teaching. As one of the PoTs mentioned, *"In terms of the Research Professors I think some of them listen to us. … We've shown them different things that you can do in class."* In addition, PoTs noted that junior faculty members were more active in seeking advice and support while being more receptive to their suggestions and open to changing their teaching methods. One of the PoTs stated:

> *I think slowly we're changing it. I see some of the new Assistant Research Professors and Associate Research Professors are starting to pick up and do some interesting things. I think it's because the Professors of Teaching have changed the conversation a little bit.*

Furthermore, when asked whether they were seeing any change in their departmental colleagues in terms of their teaching, PoTs noted gradual progress in moving away from teacher-centered approaches (e.g., lecturing) to more student-centered learning (e.g., student presentations and group work). Below is a PoT describing the change they observed:

> *We started to see a few professors actually trying to do flipped classrooms. We're starting to see them bring in, and at least do polling in the large lower division lectures. We've seen some things in the graduate classes too where they've actually done things where the students are giving presentations instead of going in there and having a lecture.*

Thus, both RPs and PoTs identified specific examples of how RPs' conceptions of teaching and learning were influenced to higher levels by their PoT colleagues.

Discussion and implications

This study aimed to uncover the conceptions of teaching and learning, instructional practices, and learning environments fostered by individuals in two faculty roles, the teaching-focused, Professors of Teaching, and traditional, Research Professors, in a single STEM department at a large-enrollment, minority-serving research university. Our findings revealed that PoTs' conceptions were situated more towards complete on the limited to complete spectrum, while RPs generally held intermediate conceptions of teaching and learning. In their courses, PoTs focused on helping students to acquire knowledge and develop skills that could be applicable both in and outside of the classroom. RPs' conceptions, on the other hand, emphasized the importance of delivering knowledge and helping students develop skills that would be applicable to the next course in the sequence. Furthermore, PoTs implemented more student-centered pedagogies, included active learning elements in their courses, and constructed more learner-centered syllabi. RPs also tried to incorporate active learning in their teaching, although to a lesser degree. These findings are in alignment with our model (Fig. 1).

Another distinction between PoTs and RPs was related to their perceptions of how much an instructor could influence their students. In particular, both PoTs and RPs expressed their beliefs as to whether the interest to pursue studies in the given subject was something an instructor could foster. PoTs specifically mentioned that it was their role as instructors to nurture this interest and that they intentionally connected the material to other topics that the students would learn in the future or to potential career pathways. While some RPs also mentioned attempts at sparking this interest to learn, the majority lamented that their influence was limited and that they *"can't cause somebody to learn it."* These differing beliefs reflect the current work examining instructor growth versus fixed mindsets and the impacts these beliefs can have on student success, particularly for students from minoritized populations (Canning et al., 2019; Fuesting et al., 2019; LaCosse et al., 2021; Muenks et al., 2020). There is also evidence that fixed mindset beliefs correlate with instructor-centered instructional practices and policies (Park et al., 2023).

In addition to the interview data, we compared PoT's and RP's course syllabi. We consider syllabi to be an artifact displaying how professors' conceptions of teaching and learning translate into practice. While interview data are helpful in understanding how professors think about their instructional practices and student learning, we use syllabi data to understand how such thinking is implemented into practice. The ability to triangulate these data is beneficial as there is also research highlighting the disparity between an instructor's perceptions of their practices versus their actual practices (Derting et al., 2016). While both PoTs and RPs professed to implement active learning pedagogies, RPs were also more likely to highlight the importance of lecture (Table 4). Aligned with these findings, course syllabi highlighted that PoTs' courses were also more likely to be student-centered. PoTs appeared to be more willing to meet with students compared to RPs while also encouraging collaboration or even requiring it, with only one RP mentioning collaboration as a tool for success in the course. Another distinction in the syllabi was that PoTs offered opportunities for students to regain points lost on assignments whereas RPs allowed regrading of the assignments only "to correct serious errors". As RPs were also less likely to self-report implementing student-centered practices, these syllabi distinctions are somewhat expected, and again highlight that PoTs' more complete conceptions of teaching and learning translated into different classroom experiences for their students.

Overall, it is clear that PoTs and RPs exhibited noticeable differences in regard to their conceptions of teaching and learning, instructional practices, and syllabus construction. This may seem unsurprising, due to the PoTs' role which expects these individuals to demonstrate excellence in teaching (Harlow et al., 2022). Still, a survey of PoTs across the studied university has highlighted that the vast majority are formally trained (in terms of their graduate and postdoctoral training) within their discipline, not within an educational field (Harlow et al., 2020), and thus it may not be reasonable to expect that their background training would lead to differences in their conceptions of teaching and learning. We do have evidence though that the PoT position itself carries an

expectation for these individuals to be more "advanced" in their pedagogy, and that once in this role, they make decisions to develop their pedagogical skills and knowledge (Williams & Sato, 2021). This transition was noted in our interviews as well through the critical incident questions. Most PoTs admitted to initially replicating the lecture style they had experienced. Below is how one PoT described their experience:

> *Younger, just starting out, not so self-assured, I think there was …these words of wisdom [lecture content], and how I organized them, that's what I was supposed to do for students. And I think some of it was a fear of not being in control of the situation. I didn't realize that not being in control of the situation was actually fun. That was way more enjoyable to actually have the students say something and you go, "Okay, I can see why you're saying that but…". I guess when I was lecturing, I only saw myself as a knowledge source, as somebody who was arranging their lecture notes for them, I guess.*

This quotation demonstrates the shift in the instructor's conceptions of teaching over time. This change in perspective enabled them to alter their role in the classroom—thus, the shift in conceptions, adjusted their practices. Another PoT noted that an instructor starts changing the ways they teach when they realize that the students have not had success learning through more traditional teaching methods. It appears that having reflected on their own learning experiences, which was primarily traditional lecture, most PoTs in our sample changed the way they were teaching, having made their classes more interactive and letting students take on an active role in their learning. This change in conception was also reflected in the way that these PoTs structured their assessments by minimizing multiple choice questions in tests and exams and substituting those with short answer questions and problems that required multi-stage calculations, as well as presentations and oral assignments that required students to communicate their thought processes.

The fact that this transition can occur within an individual's career also highlights the institution's responsibility to help faculty advance their conceptions of teaching and learning and push their teaching practices in a more student-centered direction to better meet the needs of students. In the United States, institutions designated as research intensive by the Carnegie Classification of Institutions of Higher Education (Shulman, 2001) are known for prioritizing research over teaching (Alpay & Verschoor, 2014; Cadez et al., 2017) where excellence in teaching is not a major driver of tenure and promotion decisions, creating less incentive to reflect on one's teaching and classroom practices. Higher education institutions need to offer appropriate incentives and professional development resources to enable instructors to reflect on their conceptions of teaching and learning, aid in their evolution, and guide the implementation of these conceptions into practice. In addition, this is where departments can leverage disciplinary experts (in this case, PoTs) to help their departmental colleagues (RPs) to advance their conceptions of teaching and learning. Our findings indicate that RPs recognized PoTs' expertise in teaching: RPs spoke of their department as a team of talented individuals with PoTs possessing expert knowledge of best practices in teaching and learning. It was also noted that junior faculty members reach out to PoTs for advice more frequently and appear to be more interested and open to implementing innovative teaching practices in their classrooms—thus identifying a potential target for whom PoTs, or other teaching-focused faculty, could be especially influential. In the same vein, graduate students, particularly those who serve as teaching assistants, may be another population through which PoTs can positively influence current and future STEM instruction. As institutions of higher education grapple with how to improve their STEM undergraduate programs, particularly to create inclusive learning environments that support the success of minoritized populations, we argue that our findings hint towards benefits of including teaching-focused faculty within departmental ranks.

Despite the positive findings regarding the PoT position, it is important that we highlight this study's limitations. First, this work focuses on instructors' conceptions and practices within a single STEM department at a single, research-intensive, minority-serving institution, which may limit the generalizability of our findings. Second, in our goal of highlighting the differences between research-focused and teaching-focused faculty, we recruited Research Professors with known ties to their Professor of Teaching colleagues. Thus, we would imagine that these RPs represent a group which may possess conceptions that align more closely with PoTs relative to an average RP. This may also skew our understanding of the impacts of PoTs as departmental change agents. In regards to drawing conclusions about the manifestation of instructor conceptions of teaching and learning in terms of their implemented practices and policies, it should be noted that we did not actually observe these practices. Instead, we leveraged instructor self-reported descriptions and course syllabi, which while recognized as significant classroom artifacts that serve as representations of course content and structure (Cullen & Harris, 2009; Goodwin et al., 2018; Palmer et al., 2016), are not the same as data capturing actual practices. We encourage future work looking to connect conceptions with

practices to collect classroom observation data from one of a number of validated instruments (Gleason et al., 2017; Kranzfelder et al., 2019; Smith et al., 2013). We also did not incorporate the student voice into our work. To better understand the impacts of instructor conceptions of teaching and learning, it is important that the student, as a significant stakeholder, is consulted to grasp how these conceptions influence the classroom environment. One potential data source might be student evaluations to explore the impacts of faculty teaching practices and attitudes. Finally, while we observed shifts in conceptions for some research subjects, future studies may explore how an instructor progresses from limited to more complete conceptions of teaching and learning throughout their work and what environmental factors influence this growth.

Conclusion

With the continued emphasis on improving STEM education and the role of faculty in this process, we aimed to compare Professors' of Teaching and Research Professors' conceptions of teaching and learning and the degree to which their classroom and course policies reflect student-centered practices. We found that interviewed PoTs articulated more complete conceptions of teaching and learning compared to RPs and discussed students' progress towards ownership of learning as opposed to RPs who focused more on transmitting knowledge to prepare students for subsequent courses. Similarly, both interviews and syllabi illustrated that PoTs enacted more student-centered policies and practices than RPs.

Our findings suggest two important points for the field. First, there are key differences in the conceptions of teaching and learning between faculty hired on to research-focused versus teaching-focused positions, and a key will be to investigate the causes of these differences and how they relate to their respective faculty positions. Second, we are optimistic that PoTs could be leveraged as agents of change to help their colleagues develop more complete conceptions of teaching and learning and implement student-centered instructional practices. In the context of the studied department, the exchange of information between PoTs and RPs appeared to be a productive collaboration, pushing the department as a whole to create more student-centered STEM learning environments.

Abbreviations

PoT	Professor of Teaching
RP	Research Professor
RQ	Research question
STEM	Science, Technology, Engineering, and Math

Supplementary Information

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Additional file 1. Syllabus assessment rubric.

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Author contributions

VR contributed to designing the study, conducted data collection, coding, interpretation and analysis, and contributed to writing, revising, and editing the manuscript. LS contributed to data coding and analysis, as well as to writing and revising the manuscript. BKS contributed to conceptualizing and designing the study, as well as to data collection, coding and analysis, writing, revising, and editing the manuscript. SML contributed to conceptualizing the study, developing the interview protocol, and to writing, revising, and editing the manuscript. NTB contributed to data coding and analysis, as well as to writing and editing the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The interview and syllabus data generated and/or analyzed during the current study are not publicly available due to the identifiable nature of the data.

Declarations

Competing interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author details

[1]Division of Teaching Excellence and Innovation, University of California Irvine, AIRB 3000, Office #3088, Irvine, CA 92697-4150, USA. [2]School of Education, University of California Irvine, Irvine, USA. [3]Department of Molecular Biology and Biochemistry, University of California Irvine, 2238 McGaugh Hall, Irvine, CA 92697, USA. [4]Department of Cell and Developmental Biology and Program in Mathematics and Science Education, University of California San Diego, San Diego, USA. [5]Department of Mechanical and Aerospace Engineering, University of California Irvine, Irvine, USA.

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