# Beliefs versus Resources: A Tale of Two Models of Epistemology

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| Journal: | *Chemistry Education Research and Practice* |
| Manuscript ID | RP-ART-10-2022-000290.R1 |
| Article Type: | Paper |
| Date Submitted by the Author: | 12-Jan-2023 |
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# Beliefs versus Resources: A Tale of Two Models of Epistemology

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Received 00th January 20xx,
Accepted 00th January 20xx

DOI: 10.1039/x0xx00000x

Compelling evidence, from multiple levels of schooling, suggests that teachers' knowledge and beliefs about knowledge, knowing, and learning (i.e., epistemologies) play a strong role in shaping their approaches to teaching and learning. Given the importance of epistemologies in science teaching, we as researchers must pay careful attention to how we model them in our work. That is, we must work to explicitly and cogently develop theoretical models of epistemology that account for the learning phenomena we observe in classrooms and other settings. Here, we use interpretation of instructor interview data to explore the constraints and affordances of two models of epistemology common in chemistry and science education scholarship: epistemological beliefs and epistemological resources. Epistemological beliefs are typically assumed to be stable across time and place and to lie somewhere on a continuum from "instructor-centered" (worse) to "student-centered" (better). By contrast, a resources model of epistemology contends that one's view on knowledge and knowing is compiled in-the-moment from small-grain units of cognition called *resources*. Thus, one's epistemology may change one moment to the next. Further, the resources model explicitly rejects the notion that there is one "best" epistemology, instead positing that different epistemologies are useful in different contexts. Using both epistemological models to infer instructors' epistemologies from dialogue about their approaches to teaching and learning, we demonstrate that how one models epistemology impacts the kind of analyses possible as well as reasonable implications for supporting instructor learning. Adoption of a beliefs model enables claims about which instructors have "better" or "worse" beliefs and suggests the value of interventions aimed at shifting toward "better" beliefs. By contrast, modeling epistemology as *in situ* activation of resources enables us to explain observed instability in instructors' views on knowing and learning, surface and describe potentially productive epistemological resources, and consider instructor learning as refining valuable intuition rather than "fixing" "wrong beliefs".

## Introduction

It goes without saying that chemistry instructors at the undergraduate level have a great deal of knowledge about chemistry. The content they teach is rich and complex and requires nuanced understandings of an incredible array of concepts and phenomena (Boothe et al., 2018; Zotos et al., 2021). However, in addition to this knowledge of chemistry, instructors also have a great deal of knowledge and beliefs - albeit potentially tacit - about teaching and learning (Hora, 2014; Gibbons et al., 2018; Popova et al., 2020). For example, consider two different instructors' understandings of teaching and learning chemistry.

*One of my most important roles as an instructor was to show people how the ideas interconnected... I should be doing something that goes, I guess, beyond just following the textbook because that's information they already can get.* –Liam

*The process of learning what a model is, what it applies to, and going through the practice of application of that model to explain an outcome and seeing that those things can be connected is the powerful thing we want our science students to do.* –James

From these quotes, we might infer that Liam conceptualizes knowledge as consisting of many pieces of information that must be connected and that James sees learning as constructing, applying, and connecting models to explain phenomena. But what can these quotes tell us about their teaching?

Research in teaching and teacher education demonstrates that teacher thinking about teaching and learning has a substantial impact on teacher practice (e.g. Baldwin & Orgill, 2019; Clark & Peterson, 1986; Mansour, 2009; Pajares, 1992; Popova et al., 2020). Teachers' implementations of curricular reforms are influenced by beliefs about teaching and learning as are smaller day-to-day decisions like how much time to spend on a particular topic or their interaction with curricular materials (Cronin-Jones, 1991; Haney et al., 1996; Wallace & Kang, 2004; Remillard, 2005; Roehrig et al., 2007). The relationship between beliefs and practice is complex and its strength may vary depending on contextual factors (Fang, 1996). Nevertheless, if we wish to support chemistry instructors

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in improving their teaching practices, the literature suggests we should attend to instructor thinking.

In this work then, we examine and unpack existing research on instructors' knowledge about teaching and learning in chemistry. First, we recast that work in terms of what has been referred to elsewhere in the science education literature as epistemologies (Hofer & Pintrich, 1997; Smith & Wenk, 2006; Havdala & Ashkenazi, 2007; Lising & Elby, 2005; Oliveira et al., 2012; Sandoval, 2005) or, more recently, epistemic cognitions (Greene et al., 2016). Specifically, epistemologies "consist of [people's] systems of beliefs [tacit or explicit] about (1) the nature of knowledge and (2) the processes of knowing" (Hofer & Pintrich, 1997). Second, we compare and contrast two models of instructor thinking, particularly in regard to their underlying assumptions about the stability and hierarchy of beliefs. We then analyze our interview data according to each model and discuss affordances and limitations of each. Finally, we consider the implications of each model on instructor professional development.

## Literature Background

Education researchers have long sought to understand aspects of instructors' thinking that give rise to their teaching practice (Abell, 2008; Clark and Peterson, 1986; Kagan, 1992; Schoenfeld, 1998; Shulman, 1986). This approach to studying teaching practice is rooted in a cognitive paradigm that "conceptualizes teaching largely in terms of [teachers'] mental life and focuses on teaching as a way of thinking with a particular set of specialized knowledge and cognitive processes" (Russ et al., 2016). Within this tradition, scholars have examined teacher's knowledge, beliefs, identities, and goals in an attempt to get "under the hood" of teacher practice (e.g., Abd-El-Khalick et al., 1998; Avraamidou & Zembal-Saul, 2010; Connor & Shultz, 2018; Connor et al.,, 2022; Kradtap Hartwell, 2019; Lederman, 1999; Loughran et al., 2004; Lutter et al., 2019; Orgill et al., 2015; Pajares, 1992; Posey et al.,, 2019; Remillard, 2005). Further, scholars have similarly focused on instructors' attitudes, beliefs, and orientations toward teaching (e.g., Gibbons et al., 2018; Heidbrink & Weinrich, 2020; Mack & Towns, 2015, 2016; Mutambuki & Fynewever, 2012; Popova et al., 2020; Vo et al., 2022).

Of specific concern within science education has been the set of knowledge and beliefs that teachers possess that is associated with knowledge, knowing, and learning. For example, participants may view knowledge as constructed from things they already know or knowledge as transferred from authority. Further, they may view science learning as either an opportunity to make sense of phenomena or to memorize information. Although researchers use a range of constructs to conceptualize these knowledge and beliefs, here we follow work in science education that characterizes them as epistemologies (Hofer & Pintrich, 1997) or, more recently, epistemic cognitions (Greene et al., 2016).

Tracing back to the 1970s, scholars have worked both to identify participants' epistemologies and also to tie those views to classroom practices of teaching and learning. Both correlational and case-study evidence suggests that epistemologies play an important role in school settings (Greene et al., 2018; Liang & Tsai, 2010; Rosenberg et al., 2006). A range of researchers across both K-12 and undergraduate settings have explored how instructors' tacit views of knowledge and knowing impact the ways they engage in teaching (Wendell et al., 2019). For example, Russ and Luna (2013) followed a high school teacher across multiple class sessions to identify how her teaching practice shifted depending on whether she viewed teaching as an opportunity to Connect Biological Ideas or Use Procedural Knowledge. Similarly, Chari and her colleagues (2019) analyzed 50 episodes of upper-division, undergraduate physics instruction to demonstrate how differing behavior of instructors was shaped by their two-dimensional epistemological understanding of problem-solving as being algorithmic/conceptual and mathematics/physics. Likewise, within chemistry education, researchers have probed the link between instructor thinking and practice. Gibbons et al. (2018) conducted a large scale study of chemistry instructors and found correlations between the instructors' beliefs about teaching and learning and reported pedagogical practices. Popova et al. (2020) focused specifically on assistant chemistry professors and similarly found some alignment between beliefs and practices.

These findings from across science education bear out the assumption that epistemology plays a strong role in shaping the teaching practices of instructors in science courses. As such, here we take as a given that epistemologies are an important piece of what lies "under the hood" in chemistry instructors' approaches to teaching and learning. Further, given the importance of epistemologies in science teaching, we as researchers must pay careful attention to how we model them in our work. That is, we must work to explicitly and cogently develop theoretical models of epistemology that account for the learning phenomena we observe in classrooms.

## Theoretical Framework

In our review of the literature, we identified two distinct approaches to modeling epistemology. In one approach, epistemologies are seen as "theories'' that people consciously possess and apply in their lives (Hofer & Pintrich, 1997; Hashweh, 1996; Davis, 2003; Kittleson, 2011; Havdala & Ashkenazi, 2007). These are often referred to as "epistemological beliefs" (Hofer & Pintrich, 1997; Schommer-Aikins, 2004). The other approach views epistemology as constructed in-the-moment from "epistemological resources" – fine-grained knowledge elements concerning knowledge and the nature of knowing (Hammer & Elby, 2002). These models differ from each other in two key aspects: the extent to which epistemologies are assumed to be stable and whether or not epistemologies develop hierarchically over time. Here, we compare and contrast the two models by describing each model and its underlying assumptions. In doing so, our work on epistemology parallels prior scholarship comparing models of student conceptual learning as grounded in (mis)conceptions versus knowledge-in-pieces (e.g. Smith III, diSessa, & Rochelle, 1994; Scherr, 2007).

### A Focus on Beliefs

Modeling epistemologies as beliefs is common across science education literature and is especially prominent in chemistry education research. For example, Popova et al. (2020) interviewed assistant chemistry professors about their beliefs and checked in two years later to see how these beliefs changed (Popova et al., 2021). Mack and Towns (2016) focused on physical chemistry instructors and interviewed them about their approach to teaching, which revealed beliefs about the purpose of their courses and the nature of knowledge in their discipline. Other studies have described instructors' beliefs in the context of specific topics, such as systems thinking (Szozda et al., 2022) and grading (Mutambuki & Fynewever, 2012).

Although studies on instructor beliefs have uncovered a variety of beliefs regarding teaching and learning, many further classify their beliefs (and/or practices) as instructor-centered or student-centered (e.g., Gibbons et al., 2018; Popova et al., 2020; Popova et al., 2021). Instructor-centered beliefs are associated with a transmission view of learning and include beliefs that students learn chemistry most effectively by taking notes during lecture or doing homework problems. In contrast, believing that students learn chemistry most effectively by working in groups or making connections between chemistry and everyday life is considered student-centered and is associated with a constructivist view of learning. In their implications, the authors of these studies discussed ways to shift instructors' epistemological beliefs *and their practice* from instructor-centered to student-centered.

Modeling epistemologies as beliefs brings with it a set of common features, which include: 1) beliefs are stable and 2) beliefs develop hierarchically over time. These assumptions are rarely stated explicitly in the literature; rather, we infer their existence by examining the methods of data collection and analysis used (see below). In this paper, we aim to bring these assumptions to the forefront so that we can determine how they impact our understanding of instructor thinking.

**Beliefs are stable.** Chemistry instructor beliefs are often treated as stable over time. We can infer this feature from the methodologies – commonly longitudinal studies – used to study these beliefs. If beliefs are assumed to be unstable over the period of minutes or hours, we would expect to see studies looking at changes during this time scale. However, if beliefs are assumed to be stable over longer periods of time (e.g., months or years), then it would be logical to collect data less frequently, perhaps once a semester or once a year. In the chemistry education literature, we mostly observe the latter. For example, Popova et al. (2021) conducted a study on assistant chemistry professors in which they compared participants' initial beliefs to their beliefs two years later, implying that changes were expected to occur on a longer time scale. Similarly, using a pre/post study design, in which beliefs are measured before and after an intervention, is reasonable if one assumes that the participants' beliefs would be essentially unchanged in the absence of the intervention for the duration of the study. Stains et al. (2015) have conducted such a study to measure the impact of a professional development program on assistant chemistry professors' beliefs. Conversely, we are not aware of any studies that characterize how chemistry instructors' thinking changes moment-to-moment.

**Beliefs develop hierarchically over time.** In the tradition of Piagetian stages of the 1960s (Piaget, 1960; Piaget, 1970) or the Expert-Novice studies of the 1980s (see Chi et al., 1988), beliefs are often modeled as moving through a progression in which they become more sophisticated over long periods of time. For example, in order to develop a chemistry version of the Colorado Learning Attitudes about Science Survey (CLASS), originally developed for physics education research, Adams et al. (2006) interviewed non-major introductory chemistry students and chemistry faculty to establish the novice and expert responses, respectively, for survey items. This method makes sense if one expects differences in beliefs between these populations and similarities within each population. Furthermore, using their survey, the authors observed a "regression in beliefs" over a semester of general chemistry. The use of the term "regression" is consistent with a hierarchical, developmental model. Returning to the example of student-centered and instructor-centered beliefs, Popova et al. (2020) identified a cluster of beliefs they labeled "transitional and consistent," which contained a mixture of student-centered and instructor-centered beliefs. The label "transitional" implies an intermediate stage within a progression. While this continuum could be utilized in a purely descriptive manner, it has typically been presented in an evaluative manner. In their implication sections, the authors of these studies discuss ways to shift instructors from instructor-centered to student-centered, communicating that the latter is more desirable than the former.

### A Focus on Epistemological Resources

In contrast to the model of epistemological beliefs commonly used in the chemistry education literature, another model of epistemology contends that it is made up of a range of smaller units of cognition known as *resources* (Hammer, 2000). Below we detail the features of this model, presenting them in contrast to the features embedded in a beliefs model of epistemology.

**Epistemological resources are unstable.** Rather than understanding epistemologies as beliefs that are relatively stable across time and place, epistemological resources are taken to be unstable across contexts. As in the case with beliefs, this assumption shows up in the methods researchers use to study and document epistemologies. Specifically, researchers will use methods that allow them to capture rich data over relatively short time spans on the order of minutes. For example, in a case study of a group of 8th graders reasoning about the rock cycle, Rosenberg and his colleagues (2006) use classroom video to demonstrate how students transition from one epistemology to another in a matter of moments based on a single comment from their teacher. Similarly, transitions in epistemologies that occur over minutes (rather than the hours, days, or years assumed in more stable models of cognition) have been documented in short excerpts (as few as 5-10 lines of transcript) in college physics classes (Scherr & Hammer, 2009; Modir et al., 2017; Irving et al., 2013; Dini & Hammer, 2017). The "framework of epistemological resources, smaller and more general than theories or traits" accommodates this dynamic contextual dependence (Hammer & Elby, 2002).

This unstable model of epistemology is rooted in a similar model of mind for conceptual understanding that may be more familiar to the reader (diSessa, 1993). Although science education began by comparing student thinking to scientific paradigms or robust scientific theories (McCloskey, 1983; Strike & Posner, 1985; Hewson & Hewson, 1984), a commitment to the notion of constructivism has demanded a move away from this (mis)conceptions model (Smith III et al., 1994). Specifically, the field is now "skeptical of treating knowledge or abilities as things one acquires and manipulates as intact units" (Hammer et al., 2005). Instead, we now think of conceptual knowledge as a complex system of many "pieces" (diSessa, 1993) which students unconsciously and dynamically assemble and disassemble in moments of thinking (Sherin, 2006; Philip, 2011; Minstrell, 1989). An epistemological resources model assumes the same is true for epistemology (Hammer, 2000; Hammer & Elby, 2002). Instead of people having "pre-compiled" (Hammer et al., 2005) views of knowledge that they call up in learning situations, an epistemological resource model assumes people compile their view of knowledge dynamically in real time by drawing on many small epistemological elements.

**Epistemological resources are differentially useful in different contexts.** One of the key premises of a model of epistemological resources is that different situations call for different epistemologies (Elby & Hammer, 2001). For example, while the NGSS (NGSS Lead States, 2013) may encourage us to have students construct their own models for phenomena, we do not necessarily want the lay public to construct their own models for the spread of COVID (in fact the state of our public health may be drastically different if fewer people had done so!). In the former context (the classroom) we may want students to adopt a view that they can be the authority on knowledge, whereas in the sphere of COVID we want people to adopt a view that the scientific community is the authority. But even this grain size is not sufficient; it is not the case that the NGSS always wants students to believe they are the knowledge authority in classrooms. There are times in which we want students to adopt a view of learning where their teachers, or the textbook, are the authority - for example, when they are told a value like Avogadro's number.

Given the diversity and variability of epistemological resources that can be useful across the contexts of teaching and learning, researchers that adopt this model of epistemology explicitly reject a hierarchical model of progressive sophistication. Instead, this model assumes that there is no "more correct" or "more expert" epistemology but that instead epistemological resources are differentially productive for learning in context. Sophistication then is not merely adopting a set of expert views but is instead the ability to "explore and discuss the differences between knowledge in multiple contexts" (Elby & Hammer, 2001). In the case of teachers, epistemological expertise involves the "awareness and judicious use of" (Russ, 2018) a range of epistemological resources. Stated differently, epistemological sophistication means possessing a suite of epistemological resources as well as a finely tuned mechanism for identifying which contexts call for which resources.

## Research Questions

In the proceeding sections, we have described assumptions that underpin two common models for epistemology (epistemological beliefs and epistemological resources). Here, we take a look at what these models let us infer about chemistry instructors' epistemologies from dialogue about their approaches to teaching and learning. Specifically, we examine whether modeling instructors' epistemologies as resources supports different implications for instructor learning than modeling instructors' epistemologies as hierarchical, stable beliefs. The following research questions guided our efforts:

1) What epistemologies do chemistry instructors articulate when talking about their approaches to teaching and learning in undergraduate organic chemistry?
2) What are the affordances and limitations of modeling instructor thinking as beliefs and as epistemological resources?

Our purpose here is to show that the model of epistemology researchers chose powerfully influences the kind of analysis they conduct on their data and what they can infer about useful approaches to supporting instructor learning.

## Methods

Our goal in this work is to examine the different tacit models of epistemology that exist in the literature to make sense of the kinds of claims each one can make about the nature of instructor thinking and learning. At its core then, we seek to contribute to the development of a cogent and well-specified framework (or theory) of instructor epistemologies; ours is a theoretical manuscript. In that way, our work parallels research by conceptual change scholars who have sought to understand the nature of student content knowledge (diSessa, 1993; Scherr, 2007; Smith, diSessa, Rochelle, 1993).

Given our parallel aims, we adopt empirical methods - particularly analytic methods - similar to those used by those scholars. Like them, we do not collect data from large-numbers of chemistry instructors and then summarize across it. Such an approach is more consistent with the goal of exhaustively mapping the terrain of knowledge elements used by participants (i.e., Taber, 2010). Instead, we use a relatively small sample of instructors and carefully examine key moments in which their epistemologies are both active and inferrable. This small number of key moments allows us to investigate the features of epistemology we hypothesize in the previous sections. In doing so, we collect and use empirical data as a “testing ground on which to refine [theoretical ideas]” (diSessa, 117) about models of epistemology in chemistry. diSessa (1993) describes this as one of the key roles that data can play in theory development.

Further, our methodological approach provides data that lends intuitive plausibility (Russ, 2018) to our claims and arguments. It is our sincere hope that, once the theory of epistemology in chemistry is better specified, other scholars (or perhaps ourselves) will take up what we have begun and begin to map the terrain using large scale studies. But first we must decide the best way to carve up the terrain; that is our goal in this theoretical work.

### Context and Participants

This study focused on introductory organic chemistry instructors at a large public university in the Midwest. Although much of the chemistry education research focuses on general chemistry, here we choose to focus on organic chemistry for two reasons – one opportunistic and one substantive. First, many discussions were taking place in the department regarding changing and/or unifying the course. As a result, there was a pre-existing need to understand the goals instructors have for their students’ knowledge construction and the means by which they believe these goals can be achieved. Second, and perhaps more importantly for our argument here, organic chemistry instructors have considerable autonomy in how they teach. Thus, we expected that more of their decisions would be based on their own epistemologies rather than institutional constraints (e.g., “I do this because my department says I have to”). This autonomy allows us to examine epistemologies more directly.

The introductory organic chemistry course at this university consists of two semesters (OChem I and OChem II). As this is a required course for chemistry, biology, and chemical engineering majors and anyone intending to pursue a career in the health field, it serves approximately 1,000 students each semester.

Organic chemistry instruction is divided among tenured professors, pre-tenure professors, and non-tenure track professors. The non-tenure track professors typically teach both OChem I and OChem II while most tenured and pre-tenure professors teach only one of these courses. All instructors use the same textbook and there is general agreement regarding the content that should be covered in each course, but each instructor has the freedom to choose their own teaching practices, author their own exams, and determine how points are allocated in their course. Some instructors have chosen to teach jointly with shared course materials and exams.

Interview requests were sent to everyone involved in teaching introductory organic chemistry over the last five years. We chose to restrict invitations to instructors who taught in the last five years because presumably these people would still remember details of how they approach(ed) teaching the course and would be involved in teaching it for several more years. Ten organic chemistry instructors responded and consented to be interviewed. They included tenured professors, pre-tenure professors, and non-tenure track professors with teaching experience ranging from one year to approximately thirty years. Four of these instructors teach both OChem I and OChem II while the other six typically only teach one of these courses.

During data analysis, we utilized an intensity sampling approach (Creswell, 2007) to select “information-rich cases that manifest [teacher beliefs] intensely but not extremely” (p. 159). This approach allowed us to select a relatively small number of cases that provided in depth information for analysis; here we focus on three of the ten professors interviewed (Table 1). These instructors represent different roles within the department and exhibit a range of epistemological resources. James is a non-tenure track professor whose interview elicited fairly frequent and consistent epistemological ideas. Liam is a pre-tenure professor who demonstrated more inconsistency in his epistemic cognition. Mark is a tenured professor whose interview was most notable for the focus on logistical aspects of teaching rather than epistemological aspects.

**Table 1.** Relevant characteristics of instructors at the time they were interviewed.

| Instructor[a] | Position | Courses Taught | Years of Teaching Experience |
|---|---|---|---|
| James | Non-tenure track | OChem I,<br>OChem II | 8 |
| Liam | Pre-tenure | OChem I | 1 |
| Mark | Tenured | OChem II | 15 |

[a]Actual names have been replaced with pseudonyms to protect identities.

### Data Collection

We chose to use interviews to infer instructor epistemologies. Interviews allowed the instructors to respond to the questions in their own words and in a more detailed manner than surveys typically allow. In recognition of the context-dependency of epistemic cognition, the interview questions were written to elicit reflections on the instructors’ particular courses rather than general thoughts on teaching. Instructors could also supply context through the use of anecdotes and examples from their experiences. Additionally, the interview questions probed a range of teaching activities and contexts, from planning to assessment to student performance. However, such reflections are still filtered through the perceptions of the interviewees; thus, they are not equivalent to direct observations of the instructors as they lecture or author assessments (Alshenqeeti, 2014). Ideally, the interviews would be coupled with observations of the instructors as they taught, wrote assessments, graded assessments, etc. In the future, we hope to collect this data. Nevertheless, we believe that interviews can help us figure out productive ways to model epistemology and can prompt instructors to consider multiple contexts for their teaching practices.

Semi-structured interviews were conducted over Zoom by the third author and lasted approximately one hour. The interviews began with questions regarding how the instructor got interested in chemistry and why they chose to stay in academia following graduate school (Q1 & Q2). Then the instructors were asked why students should take organic chemistry, what the students should learn from the course, and how the students can maximize their learning (Q3, Q4, Q8). The interview also included a discussion of assessment: how the instructors evaluate learning, what they aim to assess, and how they interpret assessment responses (Q6 & Q9). The interviews concluded with questions about if and/or how the instructors make use of teaching resources, including advice from peers and chemistry education research, and the role of evidence in changing teaching practices (Q11-Q13). The full interview protocol can be found in the appendix.

The interviews were transcribed by Zoom, and the first author corrected these transcriptions as needed to ensure they were accurate. The first author also broke up longer sections of dialogue into utterances that focused on a particular idea. These served as the units of analysis while coding.

## Data Analysis

### Strand 1: Analyzing instructor beliefs

In our first strand of analysis, we sought to understand instructors' epistemologies using a beliefs model. To do so we developed an analytic scheme by looking across the work of multiple authors who seek to characterize teacher beliefs from interviews or from their practice (Luft & Roehrig, 2007; Popova et al., 2021; Simmons et al., 1999). Although all of the authors identify a range of beliefs (e.g., beliefs about student learning/actions, beliefs about the role/actions of teachers, beliefs about content, etc), their analyses ultimately cluster teachers by patterns of responses. Further, although they each have several different clusters, ultimately the clusters are placed along a continuum where the two ends are student-centered and instructor-centered beliefs. Synthesizing across the papers we identified some common key elements of these two ends of the spectrum.

**Student-centered.** Instructors believe students learn by doing and not by listening; thus, the role of instructors involves collaborating with, facilitating, and guiding students as they construct ideas that are relevant to their lived experience from their prior knowledge.

**Instructor-centered.** Instructors believe that students learn by paying attention and listening to the instructor; thus, the role of the instructor is to provide content and experiences so they can assess if students know a set of pre-defined facts.

In addition to these two ends of the spectrum, researchers typically also included a transitional or inconsistent category when an instructor evidenced beliefs from both ends of the spectrum.

In our work here, we used the two ends as a guide for our analysis; the first two authors read through the transcripts and together assigned a code of "student-centered" or "instructor-centered" to each utterance. (Recall that an utterance was a section of dialogue concerning a single topic, typically 5-8 sentences). We restricted our analysis to questions 3-10 of the interview protocol because these questions surfaced reflections on their own teaching rather than their perceptions of the department and the field of chemistry education. Furthermore, we ignored utterances that were not epistemic in nature (e.g., "Say that one more time."). For this analysis, we relied heavily on which pronouns ("I" versus "they/them") were used in the active voice and which were used in the passive voice when referencing teaching and learning. If an utterance included both student-centered and instructor-centered beliefs, it was labeled as "both." Table 2 provides some examples from our data for each of the two clusters.

**Table 2.** Examples of utterances coded as student-centered and instructor-centered.

| Code | Example |
|---|---|
| Student-centered | *What we need to be as educators, as teachers, is people who set up the students to have those experiences I just described. We need to be creating environments where somehow students are engaged in thinking about models, using models, writing about them to explain why something happens.* |
| Instructor-centered | *I felt like one of my most important roles as an instructor was to show people how the ideas interconnected. So whenever we introduce a new idea, be very clear about what is new in this idea… with kind of a very brief review of whatever that concept is. So I think that's something that is much harder to do when you're kind of working through, um, something kind of on your own.* |

### Strand 2: Analyzing instructor resources

To describe the epistemological resources of chemistry instructors, we ground our analysis in the five-dimensional model proposed by Chinn and his colleagues (2011). We chose this model because it is, for us, the most comprehensive of all the existing models and is consistent with insights and components from other prominent scholars of epistemology (Hammer and Elby, 2002; Hofer and Pintrich, 1997; Schommer-Aikins, 2004). Below we will briefly describe each of the five dimensions.

**Epistemic Aims and Values.** Epistemic aims are the goals relating to inquiry, and epistemic values describe the relative worth of particular aims. Aims, or what others call goals (Berland et al., 2016) are an important part of characterizing a person's epistemology because they are the ends to which other aspects of epistemic cognition are directed.

**Structure of Knowledge.** The structure of knowledge refers to how knowledge is organized and answers questions like "What kind of answer should our [learning] provide?" (Berland et al., 2016). They are akin to epistemic forms (Collins & Ferguson, 1993; Hammer & Elby, 2002) which are "target structures that guide inquiry."

**Reliable and Unreliable Processes for Achieving Epistemic Aims.** Processes refer to the actions one takes to achieve one's epistemic aims. Epistemic processes are similar to Hammer and colleagues' (Hammer & Elby, 2002; Rosenberg et al., 2006) epistemological activities that help people (tacitly!) answer the question, "What are you doing?" in terms of knowledge construction or use. Processes are also consistent with what researchers in undergraduate physics education (Odden & Russ, 2018; Chen et al., 2013; Tuminaro & Redish, 2007) have called the moves in an epistemic game (Collins & Ferguson, 1993).

**Sources, Justifications, and Stances.** Sources of knowledge refers to where knowledge was obtained from, such as an expert, authority figure, textbook, or one's direct experience. Justifications for knowledge are the criteria by which a person evaluates knowledge, such as coherence with prior knowledge, logical consistency, or support with acceptable evidence. Stances toward knowledge describe a person's view on a given knowledge claim. Although Chinn et al. (2011) put these together because they are tightly linked in practice, other scholars treat these dimensions independently (Berland et al., 2016; Hammer and Elby; 2002; Tuminaro & Reddish, 2007).

**Virtues and Vices.** Epistemic virtues and vices encompass personal characteristics that either support or hinder epistemic endeavors. Few other scholars in science education discuss this dimension.

Using these categories as a guide for our coding process, the authors read each utterance of dialogue and discussed whether they saw anything that would fall into the categories. Once this was completed for the three interviews, the authors summarized their observations for each category into a succinct list of resource codes. Once individual codes were defined, the authors used the constant comparison method (Glaser & Strauss, 1967) to confirm that all utterances were coded with a stable codebook (Table 3).

**Table 2.** Epistemic Resource Codes and Examples

| Epistemic Resource Codes | Examples |
|---|---|
| **Aims and Values** | |
| Memorization | “The students then have to memorize these factoids and memorize these patterns instead of understanding the model where they don't have to memorize anything.” |
| Explanation | “I'd like to do a better job of assessing, um, is, um, actually getting some feedback myself about where they’re deriving their explanations. So like when they say this would go through SN2, um, basically how can it be explained, um, like why, why did you say SN2, or what sort of factors do you think are at play here?” |
| Problem-solving | “So, uh, for somebody interested in, um, medicine, um, first of all, I guess like a large fraction of people taking the class, I think that, um, there are sort of aspects of the, the type of problem solving we do in organic chemistry that’s really important. So, um, and sort of as specifically as I can, I guess what I feel like we're talking about is, uh, taking like a set of, uh, I guess, kind of starting criteria, like sort of the simple ideas, like steric bulk, um, electronic sort of perturbations, that have these principles and then trying to figure out how to sort of interconnect them to come up with an answer to a new sort of problem.” |
| Usefulness | “Now I have no belief that most of my students will do a distillation again after they leave my class. And I do not care if they ever do a distillation again, that's irrelevant. But I know that 100% of my students are going to apply models to explain systems. They're going to use models to predict outcomes. They're gonna use models to rationalize outcomes. We should have them engaged in doing that.” |
| **Structure of Knowledge** | |
| Pieces | “I think the important things for us to be actually getting from [the students] are like connecting concepts and that's not connecting any concepts. Um, but I think hitting at some of the individual concepts on their own is also important. Um, so making sure that they're getting those building blocks and that we're not only assessing them on connecting the building blocks. I find that’s also important.” |
| Connections | “And so I felt like one of my most important roles as an instructor was to show people how the ideas interconnected. So whenever we introduce a new idea, be very clear about what is new in this idea and what is drawing on things they've already learned, with kind of a very brief review of whatever that concept is.” |
| Hierarchy (building up) | "I think being able to connect independent concepts to address a more complex question, um, I think that's sort of a fundamental learning objective for organic chemistry.” |
| Hierarchy (underlying) | "And so, especially for these pre-professional students who may never take another science class beyond second semester organic chemistry, um, this teaches them how you master a complicated topic that demands more than just rote memorization, right? This, it really does kind of, uh, teach you that, um, cramming isn't feasible at, um, you do have to understand underlying mechanisms to really succeed in a class like this.” |
| **Reliable Processes** | |
| Accumulating | “But one of the challenges to, um, doing formative assessment, in my view, is that because we put so much content in the class, I think it, I found it very difficult to adjust, to sort of respond to the students. Um, ‘cause I would like to, if they're really struggling with the question, be able to dig in a little bit more, um, and sort of give that a little bit more time, and on some of the times that was okay and possible. Um, there certainly were other times where that wasn't going to be feasible because I had to get to the next sort of set of content.” |
| Connecting (structural) | “But even for those [students] who are reading the book, I think that my job as an instructor is to, uh, put all of this information into a, into a package that's digestible so that they can see how the inferences get drawn, to see analogies from one unit to another one.” |
| Connecting (functional) | “But I'm trying to assess, uh, whether [students] can predict reactivity or properties like acidity from molecular structure. Uh, and there, the sort of like a sub version of that, that's sort of predicting relative behavior of different structures, so being able to predict how two different mol-, how two different structure will result in two different activities.” |
| Forming | “Um, and that, I think, there's sort of a trap in organic chemistry for those students because our content is, the learning objectives are about figuring out which of these principles to be thinking about and then thinking about |

| | |
|---|---|
| | them properly. And stuff can seem clear when you have the answer, where you really wouldn't be able to derive that answer yourself… learning the process of actually solving the problem is, I think, the most important thing for being successful” |
| **Sources** | |
| Instructor | “In practice, I think most of [the students] use the lecture as the main source of information, so, you know, as much as I would like for them all to be reading the book, I think that I am a primary source of information for them.” |
| Textbook/online | So I didn't feel like my role was to define what the content was. And also there are very good resources; online textbooks are pretty good. There are lots of places [students] can get kind of that most basic information.” |
| Data | “And so I try to, I try to convey the point that this class is such a conceptual one, such a theoretical one that that learning modality [of cramming] is going to fail, and I show [the students] data from previous years to show exactly why this fails.” |
| **Justifications** | |
| Correctness | “And so then if they get [the question] right, or by and large get it right as a class, um, then I feel like I'm safe to move on [to the next topic]. If not, then that means I devote a little bit more time in the lecture to trying to clarify whatever that specific problem was.” |

## Results and Discussion

In the section that follows, we consider the affordances and limitations of beliefs and resources models of epistemology in describing instructors’ views on knowing and learning manifest during our interviews. We begin by briefly describing the instructor epistemologies elicited during the interviews, first using instructor-centered and student-centered descriptors. Then we will summarize the epistemological resources we observed using Chinn et al.’s (2011) multidimensional framework. Then we will consider the extent to which epistemologies embedded in interview dialogue were stable and the implications of treating these epistemologies as hierarchical.

### RQ1: What epistemologies do chemistry instructors articulate when talking about their approaches to teaching and learning in undergraduate chemistry?

When we coded our instructors’ beliefs as student-centered, instructor-centered, or both, we observed three qualitatively distinct profiles for our three instructors (Fig. 1). Approximately three quarters of Mark’s beliefs were deemed instructor-centered while the remaining were student-centered. The reverse was observed for James; the vast majority of his beliefs were student-centered while a few were instructor-centered. Liam’s beliefs were distributed almost equally among student-centered and instructor-centered. Therefore, if we were to adopt this model of describing instructor thinking, we would label Mark as instructor-centered, James as student-centered, and Liam as transitional.

When we coded for epistemological resources and organized them according to Chinn et al.’s multidimensional model, we identified several aims, reliable processes, sources, etc. (2011). These epistemological resources are summarized, along with examples from our data, in Table 3. The epistemic aims expressed by our instructors included memorization, explanations, and problem-solving, along with the value of usefulness. Reliable (or unreliable) processes for achieving these aims included forming (i.e., constructing one’s own knowledge based on prior knowledge), accumulating, and connecting. Connecting could be further described based on whether the instructor described how different topics relate (structural) or how causes give rise to effects (functional). These different ways of connecting knowledge were closely related to how the instructors discussed the structure of knowledge in their courses. They referenced “pieces” or “building blocks” of knowledge and articulated how making connections between them could result in more complex knowledge structures. Other times they described how the complexity could be reduced down to a few underlying pieces or fundamental ideas. Sources of knowledge referenced included the instructors themselves, the textbook, and data. We identified correctness as a commonly invoked justification for whether or not an aim had been achieved. Stances toward knowledge and virtues and vices were not observed in our dataset. Although we have described the epistemological resources observed amongst our instructors in aggregate, each of our instructors activated a variety of resources over the course of the interview. We will characterize each instructor’s ideas in more detail when we explore the extent to which they were stable in the following section.

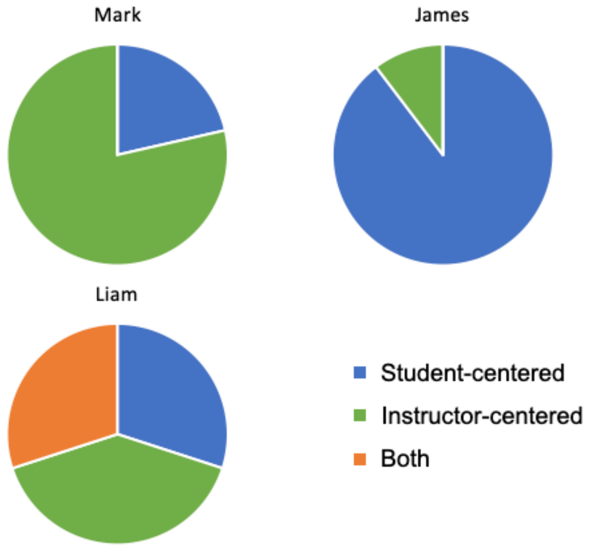

**Figure 1.** Pie charts showing the proportions of student-centered and instructor-centered beliefs expressed by the instructors in this study.

### RQ2: What are the affordances and limitations of modeling instructor thinking as beliefs and as epistemological resources?

Throughout our interviews, instructors expressed epistemological ideas relating to course design, lecture practices, assessment strategies, and interactions with students. This enabled us to explore instructor epistemologies across different topics over the span of the interview. For this sort of analysis, we focus on each instructor individually rather than looking across them.

#### Stability

We begin with James, who repeatedly espoused student-centered beliefs during his interview. James' primary goal for his students is that they engage with the practice of scientific modeling.

> *So like the process of learning what a model is, what it applies to, and going through the practice of application of that model to explain an outcome and seeing that those things can be connected is the powerful thing we want our science students to do. Because what it finally does is it gets people thinking scientifically in a meaningful way, in that they understand, "Oh, people have seen data. People have generated models that explain those data. They have then tested those models and refined them over time. And here's the best understanding we have right now. Now, there might need to be some tweaks to that down the road, but this is the best understanding we have right now. And I can take that understanding and apply it to these cases and work out what's likely to happen. And I can then test that with spectroscopy. I can test that with some tool."*

In this description of modeling, James positions his students as the constructors of knowledge – a hallmark of student-centered instruction. He wants his students to "*think scientifically*," "*to see that… things can be connected*," and "*take that understanding and apply it*."

When looking across James' interview, he repeatedly expresses this goal for his students' learning. When asked why students should take organic chemistry James' answer mirrors the one above.

> *The reason you should take organic chemistry…is that taking organic chemistry, if taught right, will help you understand that we can use some very simple, straightforward models that are accessible to students and to experts and they're the same model… We can use those same models to explain why chemical reactions happen. We can use those same simple models to rationalize why you get a particular regiochemistry or particular stereochemistry, why one product is major and one's minor, why one is seen and one is not observed in the data… That's incredibly empowering use of models to explain outcomes.*

James centralizes modeling again when referencing his role as an instructor.

> *What we need to be as educators, as teachers, is people who set up the students to have those experiences I just described. We need to be creating environments where somehow students are engaged in thinking about models, using models, writing about them to explain why something happens.*

Both a beliefs model and a resources model of epistemology work quite well for making sense of James' thinking. James' thinking about teaching appears to be consistently, and stably, student-centered since students are positioned as the modelers. Alternatively, we can state that the epistemic aim of modelling was repeatedly activated by James when reflecting on his course.

However, the other two instructors' interviews demonstrate more instability. Liam said he did not think it was his job to determine the course content and that students could obtain content from a variety of sources. In reflecting on his role as an instructor, he said,

> *We have, although we have some differences in what we teach across the different instructors, we teach a lot of the same reactions and basic principles. So I didn't feel like my role was to define what the content was. And also there are very good resources; online textbooks are pretty good. There are lots of places [the students] can get kind of that most basic information.*

Rather, he described his job as follows: "*So my role was one, I guess, make sure [the students] got some of the basic information, so sort of reviewing it a little bit, but more so than that, I thought my role was to show them how to connect concepts.*" His primary goal was not to deliver knowledge but to have students connect and use that knowledge. This goal would be considered student-centered. However, moments later in the interview, Liam shared the challenges he experienced with implementing clicker questions in lecture. He said,

> *But one of the challenges to doing formative assessment, in my view, is that because we put so much content in the class, I think it, I found it very difficult to adjust, to sort of respond to the students. 'Cause I would like to, if they're really struggling with the question, be able to dig in a little bit more and sort of give that a little bit more time, and on some of the times that was okay and possible. There certainly were other times where that wasn't going to be feasible because I had to get to the next sort of set of content.*

Liam felt pressure to - and in fact states that he does - cover the content in lecture. That goal is part of an instructor-centered mindset.

As a result of these two different statements, the beliefs model of epistemology might place Liam into a "transitional" or "inconsistent" category of beliefs. Using the lens of a resources model, we would account for the instability by noting that Liam possesses epistemic resources for understanding both himself and outside resources as a sources of knowledge and that these were activated at different times.

Liam is not an anomaly in terms of this instability. Mark similarly demonstrates instability in his thinking about teaching and learning. For example, when talking about how students can maximize their learning in his course, Mark defaults to a practical, rather than knowledge-based, perspective.

> *And so I try to, I try to convey the point that this class is such a conceptual one, such a theoretical one that that [cramming] is going to fail, and I show them data from*

> *previous years to show exactly why this fails... And I also try to tell them that, you know, that they should gear their, their studying around what the assessment is. And so if the assessment is, um, some kind of problem and a certain kinds of problems, then they should be doing those problems and those kinds of problems as part of their studying.*

In this quote, learning looks like "time on task;" his focus is on students engaging in activities (e.g., assessments) that he has designed for them, a hallmark of instructor-centered teaching (Simmons et al., 1999; Popova et al., 2020; Luft & Roehrig, 2007). However, when asked why students should take organic chemistry, Mark articulates the following:

> *...the reason that I think everyone ought to take it is that it teaches you how to deal in a more sophisticated way with drawing influences, uh, inferences from data, uh, from using data to support an argument...And so if everybody took organic chemistry, then it would sort of help them to think about how you, um, how you, uh, use data to make informed decisions, which seems like a really important thing just in general.*

He believes organic chemistry enables students to make decisions outside of the classroom by teaching them reliable processes characteristic of science such as using data. Further, he positions students as authorities who can interpret data, craft arguments, and make decisions. Making the class "relevant" for students who then engage in substantive intellectual work is a hallmark of student-centered instruction (Popova et al, 2021). Like Liam, these two quotes of Mark's would lead beliefs researchers to characterize him as "inconsistent" or transitional."

The resources model on the other hand expects this variability and treats it as something that can provide insight into Mark's teaching practice. For example, later in the interview Mark describes his approach to writing assessments which he summarizes as consisting of three general types of questions.

> *"The lowest level [type of question] is simply, you know, if you have some starting molecule, um, what reagents do you use to do some kind of a transformation?*
>
> *… [The second type of question] is what I call circle-square, um, kinds of questions, which is circle the most acidic compound, square the least, uh, acidic compound, circle the most nucleophilic compound, square the least nucleophilic compound. Right? And so, so these sorts of questions are trying to get students to think through structure-reactivity principles, to get a sense of the character of the compounds.*
>
> *…And then there are compound, there are, um, uh, questions that put everything together that has people to, uh, essentially explain an observable phenomenon, whether that is showing them a reaction and asking them to propose an arrow-pushing mechanism or giving them a phenomenon and asking them to explain why that phenomenon occurs or to rationalize the outcome. So it is very much along the lines of trying to model what a scientist does, right? If you are given an observable piece of data, how do you use theoretical constructs to rationalize that outcome?"*

The first two types of questions simply ask students for a claim, whether it's providing the correct reagents or circling the correct molecule. In the last type of question, students are asked to do intellectual work of using data, drawing inferences, and making arguments. What we see here is again instability in his epistemologies; he has resources both for seeing the epistemic aim of knowing facts (i.e., obtaining true beliefs) and the epistemic aim of having a rational model for how the world works. Rather than categorizing Mark as merely "inconsistent," the resources model encourages us to explore the range and depth of his thinking and to view that range as potentially productive for his teaching practice (see below).

### Hierarchy

Recall that if we examine the instructors' beliefs in aggregate, we see that James has mostly student-centered beliefs, Mark has mostly instructor-centered beliefs, and Liam has a mix of both. An implication of this analysis might be that James is the best instructor and that interventions are needed to shift Mark and Liam towards more student-centered beliefs.

Using an epistemological resources model of instructor thinking, we would come to a different conclusion. Since activation of epistemological resources is assumed to be context dependent, we would not treat individual resources as "good" or "bad." Rather, we would recognize situations in which they might be more or less productive. For example, consider the following quote from Mark:

> *In practice, I think most of [the students] use the lecture as the main source of information, so, you know, as much as I would like for them all to be reading the book, I think that I am a primary source of information for them. But even for those who are reading the book, I think that my job as an instructor is to put all of this information into a package that's digestible so that they can see how the inferences get drawn, to see analogies from one unit to another one.*

Since Mark positioned himself as the source of knowledge in the course, he would be described as instructor-centered and therefore less epistemologically sophisticated. Alternatively, we might notice that Mark possessed an epistemological resource for the instructor as a source of knowledge. Depending on the particular information Mark wanted to impart, this resource may be considered productive or unproductive. For example, creating space for students to "figure out" correspondence between features of spectroscopic traces and molecular structure may not be a good use of time. Organic chemists and organic chemistry learners need to be able to effectively analyze and interpret spectroscopic data (Stowe & Cooper, 2019), but they can do so by using skills and rules they are told (e.g., the n+1 rule). The goal of pulling information from spectra is to inform arguments about component(s) of a system under study. It would therefore be better to spend more class time considering consistency between possible claims and spectroscopic evidence rather than, for example, "figuring out" the n+1 rule via numerous pattern matching exercises. From this and related examples, we can conclude that viewing the instructor as a source of knowledge is neither good nor bad but more or less appropriate depending on the particular circumstances.

An epistemological resource model also allows for a much more detailed characterization of instructor ideas, which enables us to recognize the variety of ideas each individual instructor holds, rather than reduce them to a single dimension. Even though James would overall be considered student-centered, some of his beliefs are more instructor-centered. For example, he states *"[The students] have to be explaining chemical phenomena using correct models, those models have to be based on core ideas, it all has to tie together, they have to be able to do that on course-wide assessments."* The standard of justification conveyed here is correctness, which based on our knowledge of his course, means agreement with scientific canon (i.e., authority). A student-centered approach to justifying models might be consistency with data as judged by the classroom community. By labeling James as student-centered, we might not recognize the aspects of his teaching that could still be improved.

On the other hand, consider Mark, who expressed mostly instructor-centered beliefs. A closer examination reveals some student-centered beliefs. For example, when he articulated how he thinks organic chemistry aids pre-med students, he said:

> *And so, especially for these pre-professional students who may never take another science class beyond second semester organic chemistry, this teaches them how you master a complicated topic that demands more than just rote memorization, right? This, it really does kind of teach you that cramming isn't feasible, you do have to understand underlying mechanisms to really succeed in a class like this. And I think that's important, especially for the people who are going on to these higher education where they are going to have to start learning things like medicine, where, you know, simply memorizing a list of, you know, characteristics of a disease is much less important than understanding the underlying mechanism. So it really is the same kind of thought process.*

In this response, Mark stressed the importance of understanding rather than simply memorizing information. A resources model allows us to attend to these ideas.

The example of Liam arguably provides the most interesting case. Recall that Liam exhibited a mix of student-centered and instructor-centered beliefs. One method of analysis might be to place him in a "transitional" category. But treating the variability as noise ignores the interesting tensions Liam himself identified and prevents us from gaining insight into how we could support his teaching. For example, consider this quote from Liam.

> *I guess something I do a bad job, I think, of assessing, but I'd like to do a better job of assessing is actually getting some feedback myself about where they're deriving their explanations. So like when they say this would go through SN2, basically how can it be explained, like why did you say SN2, or what sort of factors do you think are at play here? Again, I worry about grading burden.*

Because he framed assessment improvement as a feedback tool for himself as the instructor and noted the implication in terms of the grading burden for himself and his TAs, we coded this as instructor-centered. But if we look more closely, we can infer that Liam was not satisfied with the epistemic aim of correct answers for his students. Rather, he wanted to know that his students understood the "why." Liam's desire to improve assessment practices to gain more insight into students' thinking and extend justifications beyond simply correct claims is an excellent starting point for improving his teaching. In this case, the barriers are not epistemic but are instead logistical. A supportive approach for Liam would be to reinforce the aim of understanding for students and provide additional graders to help him assess understanding.

## Implications and Conclusion

In this study, we have examined how two different models of epistemology lend themselves to different sorts of analysis of data on instructor thinking about learning in chemistry. Our findings suggest that each model has different constraints and affordances. We conclude by exploring those differences and their implications for professional development and research in chemistry education.

### Beliefs Model of Epistemology

**Limitations.** Our analysis above indicates a number of limitations of the beliefs model. First, the beliefs model does not account for the impact of context on instructor thinking. As our examples and literature in science education (e.g. Coffey et al., 2009; Russ & Luna, 2013) both show, the way that instructors think about learning in one context (for example when thinking about their assessments) can differ dramatically from how they think about learning in other contexts (for example when thinking about their course plans). By collapsing across time and context in analyses of instructor beliefs, this beliefs model loses this variation. While this may not be problematic in all cases (there are some instructors with stable beliefs), there are cases even in their own data (e.g., "instructor-centered and inconsistent beliefs" category in Popova, 2020) in which instructors express contradictory beliefs. In such cases, collapsing their thinking into a single belief may obscure important portions of their thinking. We can make the analogy to the use of descriptive statistics in data analysis. A beliefs model is akin to using an average - and only the average - to define a data set that may itself be fairly disparate. An average can be insufficient at best (as in the case of a distribution with long tails) and misleading at worst (as in the case of a bimodal distribution). In either case, the beliefs model misses out on portions of instructor thinking that may have relevance to their practice.

A second limitation of the beliefs model is the assumed link between those beliefs and practice. The research on beliefs uses decontextualized surveys or interviews (Gibbons et al., 2018; Luft & Roehrig, 2007; Popova et al., 2020) to elicit and analyze instructor espoused beliefs (Sandoval, 2003). In doing so, this model assumes a relationship between these decontextualized beliefs and how those beliefs will be enacted in practice. However, there is little empirical data from the literature to support such a connection between espoused beliefs and practice. As Hora (2014) articulates, "Given the lack of evidence regarding the causal relations among faculty beliefs, teaching, and student outcomes, faculty developers would be well served to not focus solely on faculty beliefs but instead to adopt a more comprehensive view of teacher growth and development" (p. 64-5)

Finally, if we assume instructor beliefs are more-or-less stable across time and place and fall on a continuum from "worse" (i.e., instructor-centered beliefs) to "better" (i.e., student-centered beliefs), a focus on characterizing and improving "bad" beliefs makes a great deal of sense. Indeed, it is common for scholars who assume beliefs are stable to categorize these beliefs via self-report surveys (Gibbons et al., 2018), concept maps (Fletcher & Luft, 2011; Lee, 2019), or interviews (Luft & Roehrig, 2007; Popova et al., 2020), and propose interventions meant to support shifts toward "better" beliefs (Mattheis and Jensen, 2014; Moore et al., 2015; Pelch and McConnell, 2016; Czajka and McConnell, 2019; Fletcher and Luft, 2011; Lee, 2019). Unfortunately, this approach potentially positions instructors as having "wrong" beliefs which require "fixing" and largely ignores potentially productive, if nascent, ways instructors have for thinking about teaching and learning. Taking such an evaluative approach can have unwanted implications for supporting instructors. Specifically, treating their thinking as "wrong" and in need of fixing can elicit defensive behavior from instructors with whom we work, making them unreceptive to our suggestions. Thus a final limitation is that a beliefs model lends itself to a deficit model of instructors.

**Affordances.** However, there are multiple affordances of the beliefs model. First, it has intuitive appeal in that it is consistent with how we talk about thinking in the everyday world. No one would argue with the notion that instructors hold beliefs about learning, and designing a survey or interview protocol asking instructors what they believe is relatively straightforward. Data analysis can be similarly straightforward since it does not require much inference to interpret statements like "I believe students should learn by reading the textbook." The clear and straightforward methodological implications of using a beliefs model means that it is more accessible to researchers or practitioners who want to study their local context.

In addition, a beliefs model of epistemology lends itself to large-scale studies. If beliefs are assumed to be relatively stable, surveys can be used to collect data, making it feasible to obtain large samples sizes and conduct statistical analyses. For example, Gibbons et al. (2018) obtained over a thousand responses to their survey probing chemistry instructors beliefs and practices and conducted a factor analysis to distinguish types of instructional styles from the responses. Furthermore, large scale studies like these seem to be particularly persuasive to administrators who might be more familiar with how to interpret quantitative rather than qualitative results.

A beliefs model also aligns with studies that utilize a pre/post design. If beliefs are assumed to be stable over time in the absence of any intervention, then any changes in beliefs can be tentatively attributed to the intervention rather than the dynamic nature of epistemology. Stains et al. (2015) conducted such a study to examine the impact of a professional development workshop on new faculty members. They concluded that their workshop was successful in shifting faculty beliefs from instructor-centered to student-centered. Like the large scale studies described above, pre/post studies in which there is a clear link between intervention and outcome may also be persuasive to outside stakeholders.

### Resources Model of Epistemology

Despite these affordances of the beliefs model, we argue for adopting a resources model that shifts away from the standard, tacit epistemology model used in chemistry education in which teachers slowly develop "better" (i.e., more student-centered) beliefs. Below we articulate the limitations and constraints of the resources model with an eye toward highlighting its generative aspects for both professional development and research.

**Limitations.** First, modeling epistemology as activation of resources is conceptually complex. Foundational work upon which the resources model is based suggests epistemologies are often tacit, variable, and context-dependent (e.g. Hammer & Elby, 2001; Russ & Luna, 2013). Thus, scholars employing a resources model have to consider what inferences about epistemology can be reasonably made from behavior, how variability should be attended to, and what features of context have the potential to send consequential messages about knowledge and knowing.

Second, analyzing the epistemological resources activated in- and across-moments is time consuming work. Researchers interested in such analyses need to carefully consider how dimensions of epistemology might be manifest in what study participants do and say. This sort of work is highly inferential. For example, some of the dimensions in Chinn and colleague's model, such as *structure of knowledge,* are almost always implicit in speech about other topics (e.g., "it is important for students to connect what they learned in the last chapter to problems they do in this unit"). Calibrating what sort of inferences about epistemology may be reasonably made from messy data takes time, training, and an understanding of learning theory - this is not an analysis that can readily be done by non-researchers. Consequently, resource analyses are low-throughput relative to analyses that rely on multiple-choice surveys. It is not practical to conduct such analyses with hundreds of instructors.

Finally, there is no "best epistemology" according to the resources model. Instead, different epistemologies have differential utility depending on the goals of the learner. Accordingly, implications from resources analyses are highly context bound and not intended to be generalized. We would not say, for example, that Mark's epistemologies are worse than James, so he needs to take workshop B to improve. Nuanced implications about, for example, the features of context that relate to participants' in-the-moment epistemologies do not lend themselves to quick summaries that can be readily digested by policymakers and administrators.

**Affordances.** The first affordance of the resources model deals with professional development. When we view instructor epistemic cognition as in-the-moment compilation of small-grain "pieces" related to knowledge and knowing, it becomes clear that no "piece" is inherently "right" or "wrong" (diSessa, 1993; Hammer, 1996; Hammer, 2000; Hammer et al., 2005; Smith III et al., 1994). Instead, clusters of epistemological resources may be more or less productive in progressing toward certain knowledge construction aims in a given moment; the resources model considers the context when assigning value to an idea. By attending to the context, we can avoid labeling instructors' beliefs as good or bad and perpetuating a deficit view of instructors. A focus on instructors' epistemological resources allows us to shift toward surfacing potentially productive resources and connections and creating contexts that signal the utility of desirable in-the-moment epistemologies. Stated differently, a resources perspective allows us to approach instructor learning as constructivists (Schafer et al., 2022). In doing so, we place instructors firmly in the role of having some expertise and ways of thinking that contribute to new ways of teaching, putting them in a position of power rather than a position of defensiveness. Our analysis of Liam and Mark in particular points to the "nuggets" of productive epistemologies that we could draw on in professional development to support their learning to teach.

Further, we know that, in principle, instructors possess productive epistemological resources for doing science that they could bring to the classroom. The instructors we interviewed are all practicing scientists with years of experience constructing, revising and communicating evidence-based causal accounts for phenomena they care about. While our interviews suggest that instructors activate some epistemological resources for doing science in the context of teaching, they do not activate others. For example, in a research setting, a model of how and why a reaction occurs is typically evaluated by consistency with experimental data, but in the classroom, such models are typically evaluated by alignment with expert models and deemed "correct" or "incorrect." We hypothesize that supporting instructors in adopting *doing science* epistemologies in school contexts could lead to enactment of more authentic, meaningful chemistry learning environments. Thus, as a potential first step toward supporting epistemologies for science (Russ, 2014) in the classroom, we advocate for providing opportunities for instructors to reflect on how they approach science and how they approach teaching. Importantly, the goal should be to make use of their experiences as scientists rather than "fix" their teaching.

The second affordance of the resources model involves its implications for research. A host of intriguing questions come into focus when one adopts a resources perspective on epistemic cognition, including: what leads instructors to compile their epistemologies in a certain way in a given moment? How can we influence those resources instructors (tacitly) see as productive? How does activation of certain epistemologies influence instructor decisions about curriculum and assessment? Seeking answers to these and related questions will allow us to understand mechanisms by which instructor epistemologies evolve, which will in turn support approaches to instructor epistemological learning that surface and build on productive resources. Such approaches would focus on helping instructors identify which epistemological resources are productive in which contexts.

Understanding, and ultimately influencing, instructor epistemologies in-the-moment and across moments is non-trivial. Epistemologies arise from a dynamic and complex system of interactions between people and materials inside and outside of the classroom. Furthermore, epistemologies cannot be understood in terms of discrete levels a person progresses through but rather as in-the-moment confluences of epistemological resources pertaining to aims for knowledge use, processes for achieving aims, sources of knowledge, and justifications for evaluating knowledge. We think the analysis described in this paper is a useful means of characterizing these resources, and the interviews we conducted surfaced some of the specific resources that might be observed. However, more research is needed to understand how instructor epistemologies arise and how they influence the design of course materials and evaluation of student knowledge products. Once we generate a working model of the relationship between instructor epistemologies and the actions they take in the context of teaching, we can study strategies for productively "tipping" instructors toward activating epistemological resources that have the potential to support students in engaging with science for the purpose of making sense of phenomena.

## Limitations of the Study

We conceive of this work as the beginning of an investigation into instructor epistemologies, and there is still much we plan to explore. The data we analyzed were collected through interviews and therefore are filtered through the perceptions of the instructors. We do not know the extent to which the epistemologies elicited through our interview protocol align with the epistemologies which shape in-the-moment instructional or assessment decisions. We would need to observe instructor's behavior as they talk to students or grade exams in order to infer these epistemologies. Furthermore, we do not claim that the epistemologies we have identified are representative of chemistry instructors everywhere nor do we claim to have uncovered all the epistemologies for teaching and learning that the interviewed instructors possess. Rather, we offer this analysis as an illustration of how one might elicit and characterize instructor ideas.

## Author Contributions

**Conceptualization:** KSD, RSR, PS, RLS

**Data curation:** KSD, PS
**Formal analysis:** KSD, RSR
**Investigation:** PS
**Supervision:** RSR, RLS
**Visualization:** KSD
**Writing – original draft:** KSD, RSR
**Writing – review & editing:** KSD, RSR, PS, RLS

## Conflicts of interest

There are no conflicts to declare.

## Acknowledgements

The authors wish to thank the organic instructors who generously shared their time and expertise with us. This study was supported by the U.S. National Science Foundation under Grant No. DUE-2225025. Funding was also provided by the Office of the Vice Chancellor for Research and Graduate Education at the University of Wisconsin – Madison with funding from the Wisconsin Alumni Research Foundation.

## Appendix: Interview Protocol

One-on-one interviews with faculty and staff are intended to elicit evidence as what interviewees view as the aims of organic chemistry learning environments, interviewee perspectives on how those environments are best designed, and how they view the role of the learner. Evidence collected from these interviews will support inferences about how the beliefs of the faculty and staff influence their approach to the curricular deliberations.

The interviews will be conducted in person or via video conference using WebEx and the audio would be recorded either via the use of a recorder or via using the record function of WebEx. Informed consent will be obtained prior to collection of any interview data.

The interview will begin with a period in which the teacher is asked to reflect on their experience as a chemist, an educator and as a student. Following this initial reflection, the interviewer will ask the questions including those written below. As this is intended as a semi- structured interview, additional questions may be added on the spot in response to ideas brought up by the interviewee. Following the period of initial reflection, the interviewer will ask the following questions, following up where needed to elicit examples salient to each question.

1. Why should students take organic chemistry as undergraduates?
2. What are the most important things that students should learn in an undergraduate organic chemistry course?
3. How do you describe your role as a teacher?
   *Description: What are the things you focus on as a teacher in order to achieve these aims?*
4. How do you know when your students understand?
   *Description: How do you find out if your students are learning the things are the focus of the course?*
5. How do you decide what works and what does not work for you as a teacher?
   *Description: How do decide if you need to change the course content, assessments or your instruction? What kind of feedback do you look for?*
6. What should students do to maximize their learning during the course?
7. What are the things that you aim to test students on while designing the assessments and why?
8. Do you think the experience of your students in your course is similar or different from your experience as an undergraduate student? Why do you think so?
9. What kind of resources do you refer to inform your teaching? Do you refer to chemistry education research to inform your teaching? Why/Why not?
10. Do you think chemistry faculty reflect on and revise their practice in response to evidence? What kind of evidence convinces them that change is needed/beneficial?
    *Description: As scientists chemistry researchers must modify their beliefs and assumption if thy find evidence to the contrary. When it comes to teaching, what kind of evidence convinces the faculty that they need to modify their teaching practices? How is the nature of this evidence similar or different from the evidence in chemistry research?*
11. If a chemistry education researcher were to approach you to modify your teaching practices, what kind of evidence would he need to produce in order to convince you?

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