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**Untangling a complex relationship: Teaching beliefs and instructional practices of assistant chemistry faculty at research-intensive institutions**

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3 **Untangling a complex relationship: Teaching beliefs and instructional practices of assistant**  
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5 **chemistry faculty at research-intensive institutions**  
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3       Abstract: In this era of instructional transformation of Science, Technology, Engineering, and  
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5 Mathematics (STEM) courses at the postsecondary level in the United States, the focus has been  
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7 on educating science faculty about evidence-based instructional practices, i.e. practices that have  
8  
9 been empirically proven to enhance student learning outcomes. The literature on professional  
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11 development at the secondary level has demonstrated a tight interconnectedness between ones'  
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13 beliefs about teaching and learning and one's instructional practices and the need to attend to  
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15 faculty's beliefs when engaging them in instructional change processes. Although discipline-  
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17 based education researchers have made great strides in characterizing instructional practices of  
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19 STEM faculty, much less attention has been given to understanding the beliefs of STEM about  
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21 teaching and learning. Knowledge of instructors' thinking can inform faculty professional  
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23 development initiatives that encourage faculty to reflect on the beliefs that drive their classroom  
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25 practices. Therefore, this study characterized the interplay between beliefs and instructional  
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27 practices of nineteen assistant chemistry professors. Luft and Roehrig's Teaching Beliefs  
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29 Interview protocol was used to capture beliefs; classroom observations and course artifacts were  
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31 collected to capture practices. Clear trends were identified between faculty's beliefs  
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33 (characterized through constant-comparative analysis and cluster analysis) and practices  
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35 (characterized with Blumberg's Learner-Centered Teaching Rubric). Overall, beliefs of most of  
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37 the participants were somewhat aligned with their instructional practices, with the exception of  
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39 one cluster of faculty who held student-centered beliefs, but received only moderate scores on  
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41 the Learner-Centered Teaching Rubric.  
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## Introduction

The discipline-based education research (DBER) community in the United States (US) has provided ample evidence of the positive impacts that the use of evidence-based instructional practices has on student learning outcomes (Freeman *et al.*, 2014). Consequently, governmental and professional organizations have supported a wave of instructional reforms and many higher education institutions have taken on to themselves to transform their instructional practices in STEM undergraduate courses. The DBER community has informed these reform efforts by characterizing their impact on faculty's practices and thought processes and by identifying contextual factors that influence faculty's instructional decisions (e.g., Shadle, Marker, & Earl, 2017; Stains *et al.*, 2018). This research has demonstrated the challenges in helping faculty adopt new practices and how little transformation has occurred in most STEM disciplines in the US, with chemistry having the lowest level of transformation.

Instructional transformation has been extensively studied at the secondary level and many of the findings could provide meaningful insight to current efforts in higher education. One of these findings that has been understudied in DBER is the tight interconnectedness between one's instructional practices and ones' beliefs about teaching and learning and the need to pay attention to instructors' beliefs during professional development programs and reform efforts (Feyzioğlu, 2012; Hora, 2014; Şen & Sarı, 2018; Wong & Luft, 2015). Indeed, the DBER community has expanded a great effort to characterize instructional practices but has given much less attention to capturing STEM faculty's beliefs about teaching and learning. Studies on beliefs fall into three main categories: characterization of beliefs, measure of the impact of instructional reforms on participants' beliefs, and exploration of the relationship between beliefs and practice.

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3 Studies aiming to characterize teaching beliefs have focused on various types of instructors,  
4 including pre-service teachers (e.g., Mavhunga & Rollnick, 2016), secondary science teachers  
5 (e.g., Fletcher & Luft, 2011), undergraduate students (e.g., Pratt & Yeziarski, 2018), graduate  
6 teaching assistants (GTAs) (e.g., Lee, 2019), postdoctoral scholars (e.g., Chapman & McConnell,  
7 2018), and university faculty (e.g., Hora, 2014). Most of these studies characterize beliefs along  
8 the continuum from teacher-centered to student-centered, where teacher-centered side refers to  
9 beliefs that support the transmission model of learning (i.e., students receive knowledge from the  
10 teacher), whereas student-centered side represents beliefs that students construct knowledge  
11 when actively engaged in the educational process and when assuming responsibility for their  
12 own learning (Luft & Roehrig, 2007). Transitional beliefs represent the midpoint along this  
13 continuum. For example, Gardner and Parrish (2019) explored beliefs of biology GTAs and  
14 found that, on average, most of their participants held transitional beliefs about teaching and  
15 learning. On the other hand, Chapman and McConnell (2018) reported that geoscience graduate  
16 students and postdoctoral scholars in their study held a range of beliefs from instructor-centered  
17 to student-centered. Some studies highlighted that the same individual can hold different beliefs  
18 about processes of teaching and learning. For example, Feyzioglu (2012) reported that most  
19 science teachers in their sample held transitional beliefs about teaching and teacher-centered  
20 beliefs about learning, whereas Wong and Luft (2015) found that science teachers in their study  
21 held more teacher-centered beliefs about teaching and more student-centered beliefs about  
22 learning. Other studies reported that pre-service science teachers, undergraduate students  
23 conducting outreach activities, and GTAs held teaching beliefs that are contradictory to the  
24 standards of contemporary literature on the best practices of teaching and learning (Gormally,  
25 2016; Phelps & Lee, 2003; Pratt & Yeziarski, 2019). Our review of studies characterizing beliefs  
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3 points to a lack of focus on STEM faculty in general, chemistry faculty in particular, and  
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5 inconsistencies in results across different STEM disciplines when the same type of instructor is  
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7 investigated (e.g., GTAs).  
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10 Another group of studies has investigated the impact of interventions (e.g., professional  
11 development programs, pedagogy courses, adoption of student-centered teaching materials) on  
12 teaching beliefs. These studies suggest that some of the interventions were successful at shifting  
13 beliefs towards the student-centered side of the continuum (Czajka & McConnell, 2019;  
14 Mattheis & Jensen, 2014; Moore *et al.*, 2015; Pelch & McConnell, 2016), whereas others failed  
15 to promote and sustain this shift (Fletcher & Luft, 2011; Lee, 2019). For instance, after an  
16 intervention targeting science teachers' topic specific pedagogical content knowledge, Mavhunga  
17 and Rollnick (2016) reported that not all of the participants demonstrated a shift towards more  
18 student-centered beliefs. Fletcher and Luft (2011) reported that, after participation in a teacher  
19 preparation program, teachers in their study initially showed a shift to more student-centered  
20 beliefs, but ultimately returned to traditional beliefs by their first year in the classroom.  
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35 Although the literature demonstrates a tight interconnectedness between ones' beliefs about  
36 teaching and learning and one's instructional practices (Czajka & McConnell, 2016, 2019),  
37 relatively few studies have closely examined this relationship. Douglass and colleagues  
38 investigated the relationship between GTAs' beliefs and practices and reported that GTAs'  
39 beliefs were consistent with their practices, exhibiting traits belonging to two primary categories:  
40 mostly teacher-centered and transitional (Douglas, Powell, & Rouamba, 2016). Other studies,  
41 however, reported the opposite finding and identified a misalignment between teaching beliefs  
42 and instructional practices (Addy & Blanchard, 2010; Bennett & Park, 2011; Dolphin &  
43 Tillotson, 2015; Mansour, 2013; Şen & Sarı, 2018). For example, Addy and colleagues, who  
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3 analyzed beliefs and practices of a different sample of GTAs, reported that half of the  
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5 participants held transitional beliefs, yet displayed fairly traditional, teacher-centered teaching  
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7 (Addy & Blanchard, 2010). One methodological weakness of most of these studies is their  
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9 characterization of instructional practices solely through classroom observation field notes or  
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11 video observations of instructional practices. The face-to-face time comprises only a small  
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13 portion of the time instructors engage students with the content. Therefore, more comprehensive  
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15 methods to characterize students' experiences with a course are necessary to more accurately  
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17 capture instructional practice.  
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21 As is evident from the literature reviewed above, currently there is little alignment between  
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23 previous findings obtained in various contexts (i.e., with different samples, in different cultural  
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25 backgrounds and educational settings). More research is needed to augment the body of literature  
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27 on teaching beliefs and their relationship to instructional practices to detect a more consistent  
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29 signal across studies performed in different educational contexts. At the same time, although a  
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31 substantial body of literature shed light on teaching beliefs at the secondary level, beliefs might  
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33 differ at the postsecondary level because unlike K-12 teachers, university instructors often do not  
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35 have specialized training in teaching. Similarly, beliefs of faculty might also differ from beliefs  
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37 of teaching assistants who may not have a lot of autonomy in the classroom/laboratory. This  
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39 exploratory study aims to contribute to the relevant body of literature by characterizing the  
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41 instructional beliefs and practices of assistant professors in chemistry at research-intensive  
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43 institutions in the United States. The focus on a particular STEM discipline and a particular stage  
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45 of one's academic career will help advance this field of research since isolating the investigation  
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47 to one specific population of one discipline (chemistry) helps discover in-depth findings without  
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49 wondering if broader context is driving the variability among participants. In addition, unlike  
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3 other studies that investigated beliefs of experienced and/or exemplary faculty (Kane, Sandretto,  
4 & Heath, 2004; Padilla & Garritz, 2015) or beliefs of faculty with a range of teaching  
5 experiences (Czajka & McConnell, 2019; Hora, 2014; Moore *et al.*, 2015), this study  
6 characterizes beliefs of novice faculty specifically. This provides a focus on a particular  
7 demographic of chemistry instructors whose beliefs about teaching and learning might still be  
8 developing and are more prone to change. Along with a thorough analysis of beliefs about  
9 teaching and learning, this study provides a comprehensive analysis of instructional practices, by  
10 characterizing both video observations and course artifacts. In particular, this study seeks to  
11 address the following research questions that pertain to assistant chemistry professors from  
12 research-intensive institutions:  
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- 26 1. What are assistant chemistry professors' beliefs about teaching and learning?
- 27 2. What is the relationship between assistant chemistry professors' beliefs about teaching  
28 and learning and instructional practices?  
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### 33 **Theoretical Frameworks**

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35 Kagan (1992, p. 65) defined beliefs as “tacit, often unconsciously held assumptions about  
36 students, classrooms, and the academic material to be taught,” which directly impact how content  
37 is presented to students. Kagan’s definition highlights that beliefs are held to be true and that  
38 they guide behavior. Over time, an individual develops a system of beliefs that is composed of  
39 multiple beliefs that are not independent of each other. The earlier beliefs in this network are  
40 held more strongly and are resistant to change. Other key characteristic of beliefs is that they  
41 form on the basis of evaluation and judgement and are inherently subjective. Interestingly, one  
42 can hold contradicting beliefs, which may trigger a feeling of dissonance (Pajares, 1992).  
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3 Beliefs are an important feature of multiple contemporary empirical models on instructional  
4 practices, including the Consensus Model of Pedagogical Content Knowledge (Gudmundsdottir  
5 & Shulman, 1987; Neumann, Kind, & Harms, 2018; Shulman, 1986), the Teacher-Centered  
6 Systemic Reform Model (Gess-Newsome, Southerland, Johnston, & Woodbury, 2003), and the  
7 Interconnected Model of Teacher Professional Growth (Clarke & Hollingsworth, 2002). All  
8 three models highlight the influence of instructors' beliefs on their classroom practices.  
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11 The Consensus Model of Teacher Professional Knowledge is composed of four main  
12 components: 1) domain of teacher professional knowledge bases, which includes content  
13 knowledge (CK) – knowledge of disciplinary concepts, theories, and principles, and pedagogical  
14 knowledge (PK) – general knowledge of educational purposes and methods of teaching, learning,  
15 and assessment (Fernandez, 2014); 2) domain of topic-specific professional knowledge (TSPK) –  
16 knowledge of best practices of teaching and learning of a specific topic (Stender, Brückmann, &  
17 Neumann, 2017); 3) domain of classroom practice, which includes classroom context and  
18 pedagogical content knowledge (PCK) – combined knowledge of content and pedagogy that  
19 enables delivery of a subject matter in a form that is comprehensible for learners (Connor &  
20 Shultz, 2018); and 4) domain of student outcomes (Neumann *et al.*, 2018). The model identifies  
21 “amplifiers and filters” that influence the relationships between some of these domains. In  
22 particular, beliefs about teaching and learning are shown to play an influential role between the  
23 domain of TSPK and the domain of classroom practice, emphasizing that beliefs impact both  
24 teacher knowledge and behavior (Schultz, Lawrie, Bailey, & Dargaville, 2018).  
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49 The Teacher-Centered Systemic Reform Model provides a framework for understanding  
50 change (or lack thereof) as an outcome of classroom reform initiatives (Gess-Newsome *et al.*,  
51 2003). According to this model, in order to achieve desirable outcomes, reform efforts need to  
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3 take into account and target one or more of the following domains: 1) contextual factors (e.g.,  
4 cultural context, school context, classroom context), 2) teacher personal factors (e.g.,  
5 demographic profile, years of teaching experience), and 3) teacher thinking, which includes  
6 knowledge and beliefs about teaching, students, and content. Teachers' knowledge and beliefs  
7 are at the center of this model and connect to all other domains, which highlights the robust link  
8 between teacher beliefs and teacher inclination to make changes to their teaching.  
9

10  
11 The Interconnected Model of Teacher Professional Growth describes another mechanism  
12 through which a teacher change can occur, where change is defined as growth or learning. The  
13 model suggests that in order for change to be possible, at least one of the following four domains  
14 need to be impacted: 1) the external domain (e.g., participation in a workshop), 2) the personal  
15 domain (e.g., beliefs, knowledge), 3) the domain of practice (e.g., classroom experimentation),  
16 and 4) the domain of consequence (e.g., student learning outcomes). The model illustrates the  
17 complex non-linear nature of the relationships between these domains, as change in one domain  
18 can promote change in another domain through the mediating processes of reflection and  
19 enactment (Clarke & Hollingsworth, 2002). According to this model, change in the beliefs  
20 system may promote change in the domain of practice and teacher professional growth.  
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## 40 **Methods**

### 41 *Sample*

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45 Nineteen assistant chemistry professors participated in this Institutional Review Board  
46 approved investigation. All participants were from high or very high research institutions  
47 according to the Carnegie's classification (Center for Postsecondary Research) and were located  
48 across fifteen different states in the US, spanning all four of the regional divisions distinguished  
49 by the US Census Bureau (U.S. Department of Commerce): 5 universities in the Northeast, 4 in  
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the Midwest, 6 in the South, and 4 in the West. A code number was created for each participant in order to protect their identities.

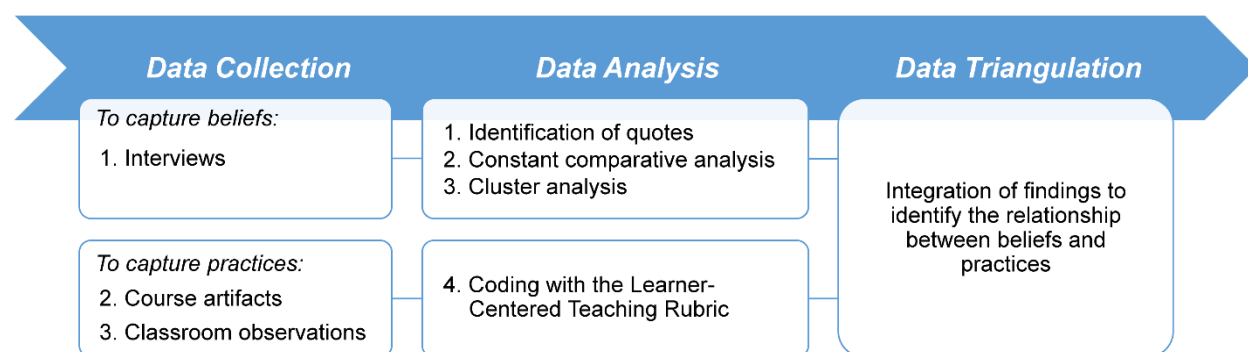
Faculty were recruited while attending the Cottrell Scholars Collaborative New Faculty Workshop (CSC NFW) (Baker *et al.*, 2014). Detailed demographics for the sample are shown in Table 1. Chemistry courses taught by faculty participants during data collection ranged from introductory undergraduate courses, such as general and organic chemistry, to advanced graduate courses, such as chemistry of polymers and mechanisms of chemical reactions.

Table 1 – Descriptive demographics for the sample.

<b>Demographic Variables</b>	<b>Faculty, <i>n</i></b>
<b>Sex</b>	
Female	10
Male	9
<b>Course level taught</b>	
Graduate	10
Undergraduate	9
<b>Year teaching</b>	
First	8
Second	5
Third	3
Fifth	3

### *Data Collection*

Figure 1 – Research design of this study.



The individual steps of this study's research design are summarized in Figure 1. Faculty participated in semi-structured, think-aloud interviews that were conducted by the first and third

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3 authors (Drever, 1995; Patton, 2002). The third author interviewed three participants in Fall 2016  
4 and ten in Spring 2017; the first author interviewed six participants in Fall 2018. The interview  
5 protocol utilized the modified Teacher Belief Interview (TBI) (Luft & Roehrig, 2007). The TBI  
6 protocol used in this study excluded one of the original seven questions and included three  
7 additional questions. Thus, the modified protocol included nine questions that elicited faculty's  
8 beliefs related to how learning occurs, how to know when students understand, what the  
9 instructor's role in the classroom is, and several other items (full interview protocol can be found  
10 in the supplementary material, Table S2). On average, the interviews lasted forty minutes.  
11 Because this population was geographically diverse, multimedia-based programs (e.g., Skype,  
12 Zoom) were used to interview the faculty participants. An audio recorder was utilized to record  
13 the data.  
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28 Besides collecting interview data, we also collected participants' classroom observations and  
29 course artifacts associated with the teaching of one unit/chapter in their courses. All participants  
30 were mailed a video camera and a tripod to videotape one unit/chapter of their choice. Faculty  
31 were then asked to share their course artifacts, which included: syllabus, any materials used in  
32 class while covering the selected unit/chapter, as well as any assessment tools (homework,  
33 quizzes, and exams) that were used to assess student understanding of the selected unit/chapter.  
34 Each faculty received a \$50 gift card to compensate them for their time.  
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#### 45 *Analysis of Interviews*

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47 Once transcribed verbatim, the interviews were read by the first, fourth, and fifth authors to  
48 identify the beliefs about teaching and learning expressed by the faculty participants. However,  
49 upon reading through the transcripts, the researchers realized that most of participants' responses  
50 described their *classroom practices* and only part of the responses expressed *beliefs* about  
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3 teaching and learning. This is not surprising, as beliefs have been regarded in the literature as a  
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5 “messy construct,” confusion around which centers on the difficulty to distinguish between  
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7 beliefs, pedagogical knowledge, and pedagogical practices (Pajares, 1992). As the designers of  
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9 the original TBI protocol have admitted, in their desire to elicit beliefs, they might have  
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11 “inadvertently captured behavioral intentions” of teachers in their study (Luft & Roehrig, 2007,  
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13 p. 43). A similar pattern was observed in this study. Therefore, the first, fourth, and fifth authors  
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15 read through each of the transcripts to identify quotes that communicated participants’ beliefs  
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17 about teaching and learning (i.e., not descriptions of *what* they are doing in their classrooms, but  
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19 explanations of *why* they are doing it). To capture as many quotes that communicated beliefs as  
20  
21 possible, the first and fifth authors individually identified and then compared all of the quotes  
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23 from questions 1-6. Similarly, the first and fourth authors individually identified and then  
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25 compared all of the quotes from questions 7-9. These efforts bolstered reliability of the findings  
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27 by reducing the number of missed quotes that communicated beliefs about teaching and learning  
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29 and resulted in the identification of 174 quotes across the nineteen interview transcripts.  
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35 The first, fourth, and fifth authors read through the identified quotes to generate the first  
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37 version of the codebook that consisted of descriptive codes (a short phrase that summarizes a  
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39 passage of qualitative data) (Saldaña, 2013). All of the identified quotes were then uploaded to  
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41 NVivo 12 to be stored, organized, and inductively coded using the first version of the codebook  
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43 (Bazeley & Jackson, 2013; Creswell, 2003; Patton, 2002). The first, fourth, and fifth authors  
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45 collaboratively coded the data. The process of coding was accompanied by writing reflective  
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47 memos in order to capture researchers’ thoughts about the data to assist in the communication  
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49 between the investigators (Birks, Chapman, & Francis, 2008). The first author was assigned the  
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3 responsibility of codebook editor to create, update, and revise the master codebook upon the  
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5 discussions of coding with the team members.  
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8 The coding process underwent several cycles. Preliminary analysis included the three  
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10 researchers independently coding quotes from the first two participants using the first version of  
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12 the codebook. During a debriefing session the codes were revised, unique cases were discussed,  
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14 and the second version of the codebook was created. In the second cycle of coding, the three  
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16 researchers coded three more transcripts. At a follow-up debriefing session, the coders again  
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18 discussed their coding process to make sure that they agree and remain consistent with their  
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20 assignment of particular codes to particular data. At this stage, the coders engaged into constant  
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22 comparative analysis, where they compared codes and explored their relationships to integrate  
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24 them into meaningful categories and themes (Bradley, Curry, & Devers, 2007). Upon reflection,  
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26 the third version of the codebook that captured the organizational framework of codes and  
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28 categories was created and applied to the rest of the data by the first author. Once coding was  
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30 complete, the fifth author examined all of the first author's coding applied to questions 1-6, and  
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32 the fourth author examined all of the coding applied to questions 7-9. At a number of follow-up  
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34 debriefing sessions, the team members discussed and examined every case of disagreement on  
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36 coding until researchers reached a 100% interpretive convergence (Saldaña, 2013).  
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42 The conformability (degree to which the results of an inquiry could be confirmed by other  
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44 researchers) and dependability (stability of findings over time) of the analysis were ensured  
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46 through keeping a careful record of audit trail notes that captured methodological procedures,  
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48 data reduction steps, and data reconstruction products (Anney, 2014; Shenton, 2004). The  
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50 credibility of the results (confidence in the rigor of the findings) were ensured through analyst  
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3 triangulation, as frequent debriefing sessions helped the researchers address any biases and  
4 assumptions brought to the interpretative analysis (Anney, 2014; Pandey & Patnaik, 2014).  
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8 To further explore patterns in the belief systems of the research participants, an  
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10 agglomerative hierarchical cluster analysis was conducted to classify faculty based upon the  
11 overall profile of their beliefs about teaching and learning. By running a matrix coding query in  
12 NVivo, a table illustrating what beliefs were expressed by each participant was generated, in  
13 which “0” showed absence of a belief and “1” showed presence of a belief. This categorical,  
14 nominal data was then uploaded to IBM SPSS 25 to perform cluster analysis. The agglomerative  
15 procedure began with each participant representing an individual cluster and then successively  
16 merging clusters together until a hierarchy of nested groupings was created (Frades &  
17 Matthiensen, 2010). Since the data was nominal, Pearson’s correlation similarity measure was  
18 selected to measure the association between the variables (Wilks, 2014).  
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### 30 31 *Analysis of Classroom Observations and Course Artifacts*

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33 Blumberg’s Learner-Centered Teaching Rubric (LCTR), which was developed as a tool for  
34 instructors’ self-assessment of their teaching, was utilized to analyze participants’ classroom  
35 observations and course artifacts (Blumberg, 2009). The rubric was used to evaluate video  
36 observations of two class periods taught by each participant (resulting in a total of 38 videotaped  
37 classes), as well as each participant’s course syllabus, lecture notes used during the two  
38 videotaped classes, and multiple assessments (e.g., homework, midterm exam, final exam, etc.)  
39 that were used to measure student understanding of the material introduced during the  
40 videotaped classes. The rubric is composed of five dimensions: I. the function of content, II. the  
41 role of the instructor, III. the responsibility for learning, IV. the purposes and processes of  
42 assessment, and V. the balance of power. Each dimension consists of several components. The  
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3 original rubric was modified to exclude components that were not relevant for the analysis of the  
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5 obtained classroom observations and course artifacts. For example, within the dimension of the  
6  
7 purposes and process of assessment, we excluded the component of “justification of the accuracy  
8  
9 of answers.” Often grading disagreements are discussed during office hours or after class. Since  
10  
11 our video records captured only classroom practices, we could not analyze any discourse that  
12  
13 occurred after class or during office hours. Thus, the modified rubric included 14 different  
14  
15 components across the five dimensions (the modified rubric can be found in the supplementary  
16  
17 material, Table S4).  
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19

20  
21 Instructors’ classroom practices and course artifacts were coded across the 14 components  
22  
23 using a four-point scale: “1” for employing teacher-centered approaches, “2” for showing lower-  
24  
25 level transitioning to learner-centered approaches, “3” for showing higher-level transitioning to  
26  
27 learner-centered approaches, and “4” for employing learner-centered approaches. Here, the  
28  
29 teacher-centered approaches refer to using lecture as the main method of teaching, whereas  
30  
31 learner-centered approaches imply the use of various methods that shift the role of the instructors  
32  
33 from givers of information to facilitators of student learning (Blumberg, 2009). The first and the  
34  
35 second authors simultaneously coded the video observations and course artifacts of four  
36  
37 participants. Each coding session was followed up by a debriefing session, where the researchers  
38  
39 discussed their assignment of the points for each of the components and resolved any  
40  
41 disagreements. After high coding consistency was achieved between the researchers, they  
42  
43 independently coded the video observations and course artifacts of seven more participants each.  
44  
45 Note that one participant has been excluded from this analysis because the researchers were not  
46  
47 able to obtain the syllabus for their course.  
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## 53 Results

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*Types of Beliefs about Teaching and Learning*

Table 2 – Themes, categories, and codes that capture beliefs of assistant chemistry professors. Note that the total number of instances for each theme is greater than the number of faculty in this study ( $N = 19$ ) because one participant could express multiple beliefs and, therefore, be assigned to multiple codes within one theme.

<b>Theme I: Beliefs about Students</b>		
<b>Category</b>	<b>Code/Belief</b>	<b>Faculty, <math>n</math></b>
Highlighting student differences ( $n = 12$ )	Different students possess different ability to grasp the material	10
	▪ With help students can get better	6
	▪ Instructor does not aim to reach all students	4
	Different students put in different level of effort	4
	International students are reluctant to participate	1
	Non-major students are intimidated by chemistry	1
General to all students ( $n = 8$ )	Humans have limited attention spans/working memory capacity	3
	Students need to assume responsibility for their learning	3
	Students are afraid to be judged by their peers	2
<b>Theme II: Beliefs about How Students Learn</b>		
<b>Category</b>	<b>Code/Belief</b>	<b>Faculty, <math>n</math></b>
Mechanisms through which learning occurs ( $n = 17$ )	Learn better by doing/thinking, not listening	8
	By listening to the instructor	6
	When making connections between concepts	5
	By paying attention	4
	By repetition	4
	When applying their knowledge	3
	When being conceptually engaged	2
	When being reflective	1
	When being conceptually challenged	1
Context in which learning occurs ( $n = 13$ )	Can learn from each other	10
	Learn best with instructor's guidance	4
	Can learn outside of class	5
	Cannot learn outside of class	1
<b>Theme III: Beliefs about Content</b>		
<b>Category</b>	<b>Code/Belief</b>	<b>Faculty, <math>n</math></b>
Selection of content to prepare students for their future ( $n = 13$ )	Real-world applications of what students learn	9
	Incorporating literature or authentic content	6
	Exposing students to a broad range of topics	2
	Providing examples that help students remember the topic	2
	Content that will make students more interested	1
The goal is student understanding, not content coverage ( $n = 11$ )	Focus on foundational concepts	9
	Teaching too much content is bad for students	7
	Curriculum is a flexible agenda	3
Curriculum is a fixed agenda ( $n = 5$ )	Need to equip students for future courses	4
	Need to equip students for the ACS exam	1

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3 Three themes that cut across the entire data corpus were identified through constant-  
4 comparative analysis: Beliefs about Students, Beliefs about How Students Learn, and Beliefs  
5 about Content. The codes within each of these themes were grouped into meaningful categories.  
6  
7 Note that the terms “beliefs” and “ideas” are used interchangeably in the section below.  
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12 *Beliefs about Students.* Beliefs about Students fell into two categories: beliefs that highlight  
13 student differences ( $n = 12$ ) and beliefs that are general to all students ( $n = 8$ ). The unique  
14 individual beliefs under these two categories are presented in Table 2.  
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19 The first category of Beliefs about Students captured beliefs that highlight student  
20 differences. The most prevalent belief under this category was the idea of heterogeneous  
21 distribution of intelligence (Blackwell, Trzesniewski, & Dweck, 2007). Our data suggested that  
22 some faculty in our study held growth mindset beliefs (i.e. beliefs that intelligence is a malleable  
23 quality that can be developed), whereas others held beliefs that are more aligned with the fixed  
24 mindset (i.e., view of intelligence as an unchangeable entity). Ten faculty stated that different  
25 students possess different ability to grasp the material and emphasized the distinction between  
26 “good students” and “poor students.” Six of these participants believed that with help students  
27 can improve, as in the case with participant #9. While explaining why she values group work  
28 activities and how she assigns students into groups participant #9 stated: “*Some students will be*  
29 *really good at concepts and others will be not. And I don't want all of [the] really good top*  
30 *students always bonding together... I like to randomize, so there's a good mix of abilities and*  
31 *skill levels in groups... But when I allow group work to happen, then students can start to help*  
32 *each other in terms of concepts and explanations.*” Participant #9 believed that students could  
33 help each other refine their understanding of concepts through discussion and explanation.  
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3 theory of intelligence, four participants' beliefs were closer to the fixed intelligence side of the  
4 fixed-to-growth continuum of beliefs about intelligence (Yeager & Dweck, 2012). For instance,  
5  
6 while describing student differences in respect to understanding chemical concepts, participant  
7  
8 #12 stated that she did not aim to reach all of her students: "*Some people probably digest the new*  
9  
10 *concepts more easily and some people are not, they aren't quite good at getting some things*  
11  
12 *right away. Everyone is different. So what we do is, definitely we can't take care of everyone. It's*  
13  
14 *very time consuming.*" As implied in the quote, participant #12 believed that due to the limited  
15  
16 class time, the students who were not as good at getting the concepts right away were not able to  
17  
18 keep up with the pace of content coverage and there was nothing that the instructor could do  
19  
20 about it. Four other faculty highlighted student differences in respect to the amount of effort that  
21  
22 they put into learning the material. For example, participant #19 shared: "*So I definitely have*  
23  
24 *assigned reading from the textbook that they are supposed to do before they come to class. But I*  
25  
26 *know that a majority of them don't actually do the readings.*" Similarly, participant #1 stated that  
27  
28 "*the best ones will dig in and learn it themselves. And the other ones will not.*" The remaining  
29  
30 beliefs under this category were idiosyncratic and highlighted differences among specific groups  
31  
32 of students (native vs. international, major vs. non-major).  
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40 Eight faculty expressed beliefs that were general to all students (second category). Three  
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42 faculty discussed the idea that humans have limited attention spans and/or limited working  
43  
44 memory capacity. For example, when describing how she ensured student learning, participant  
45  
46 #11 stated that during class she asked her students multiple questions because "*all people, you*  
47  
48 *know, have limited attention spans and whenever I ask questions, they'll actually, actually really*  
49  
50 *pay attention to you and then they're thinking about the question.*" Other faculty ( $n = 3$ ) believed  
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52 that in order for students to learn in the course, they needed to assume responsibility for their  
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3 learning. This belief was best embodied by participant #10 who stated: *“I can’t make them learn*  
4 *it, you know, I’m not there holding their hand while they’re actually studying so I give it to them*  
5 *the first time, I give them problem sets and quizzes and stuff to try to help them get to those*  
6 *goals, but I can’t, yeah I can’t force it into their heads, I’ve learned.”* The final belief under this  
7  
8 category was the idea that students were reluctant to participate in the educational process  
9  
10 because of the fear of being judged by their classmates ( $n = 2$ ). For example, while describing  
11  
12 her difficulties with encouraging students to ask questions, participant #19 shared that *“most of*  
13 *the time people don’t ask because they’re embarrassed to ask a question in a group so big.”*

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21 *Beliefs about How Students Learn.* Beliefs about How Students Learn fell into two  
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23 categories: mechanisms through which learning occurs ( $n = 17$ ) and context in which learning  
24  
25 occurs ( $n = 13$ ). The unique individual beliefs under these categories are presented in Table 2.

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29 The most prevalent belief under the first category was the idea that students learn better by  
30  
31 doing and/or thinking, not listening ( $n = 8$ ), as exemplified by the following quote from  
32  
33 participant #19: *“I think that if they are forced to do something on their own rather than just sit*  
34 *there and listen to me, then they actually like retain more of what we’re going over.”* These  
35  
36 participants made a clear comparison between learning by doing/thinking and learning by  
37  
38 listening and expressed their preference for the former. Interestingly, the second most prevalent  
39  
40 idea under this category was a contrasting belief to the one above. Six participants stated that  
41  
42 students learn best when listening to the instructor. For example, when asked how he maximizes  
43  
44 student learning in his classroom, participant #1 explained: *“If the lecture comes off kind of like a*  
45 *story, you know, even if it’s not in a traditional sense a story, but if it, if one thing leads to the*  
46 *next logically, I think students remember it better. And I base that simply on the fact that that*  
47 *seemed to be how I learn best.”* A related belief that students learn by paying attention was  
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3 expressed by four participants. For example, when asked to explain why he thinks that  
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5 “*presenting information in a more interesting way*” was critical for student learning, participant  
6  
7 #2 stated: “*I think that better presenting the information would keep the students more engaged*  
8  
9 *and that sort of leads to better understanding and comprehension.*” Other participants ( $n = 4$ )  
10  
11 believed that students learned by repetition, which was exemplified by participant #13: “*I think if*  
12  
13 *a concept is not practiced it will be forgotten soon after you pass that course, no matter what*  
14  
15 *grade you get... The more practice we do, the more settled that concept will be in, in our minds.*”  
16  
17 These participants valued exposing their students multiple times to the same concept or problem  
18  
19 to achieve deeper learning. Another belief, consistent with the theory of meaningful learning  
20  
21 (Novak, 1993), was the idea that students learn when making connections between concepts ( $n =$   
22  
23 5). This belief was a key point in the response of participant #10 when explaining how he  
24  
25 determined whether or not his students understood the material: “*They should be able to work*  
26  
27 *through like a challenging comprehension problem. And one of the things that I struggle with in*  
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29 *that, is that I am trying to push them towards seeing how all of these things are interconnected.*  
30  
31 *Because they really like to learn each topic in a vacuum and when they see that, oh, lipid*  
32  
33 *oxidation is connected to the citric acid cycle, to me that’s a good sign that they understand what*  
34  
35 *we’re talking about.*” Finally, a few other less prevalent beliefs that describe the mechanisms  
36  
37 through which learning occurred included idea that students learn when being conceptually  
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39 engaged, when reflecting on their learning, and when being conceptually challenged.  
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47 The second category under Beliefs about How Students Learn captured beliefs about context  
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49 in which learning occurs. The most prevalent code under this category was the belief that  
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51 students can learn from each other ( $n = 10$ ): “*I’ve given independent take-home quizzes where*  
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53 *they are encouraged to work with their classmates, again, to kind of promote discussion about*  
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3 *the topic with the idea that hopefully, if they have a misconception about a particular topic or*  
4 *idea, then working in groups will clarify some of the material”* (participant #8). Some of the  
5  
6 participants, whose responses fell under this code, believed that peer explanations sometimes  
7  
8 were even more effective than an instructor’s explanation, as was the case with participant #12:  
9  
10 *“sometimes, it’s probably more easy for them to grasp the ideas from their peers rather than*  
11 *from me.”* Others added that the *“best way to learn is to teach,”* which, in their opinion,  
12  
13 explained why not only the students who were being taught benefit from peer instruction, but  
14  
15 also the students who teach are able to deepen their understanding when explaining concepts to  
16  
17 their classmates. Four other participants expressed the belief that students learn best with  
18  
19 instructor’s guidance: *“I provide a little help so they know where to go, but that it’s still*  
20 *challenging enough that it’s interesting. I think the biggest lasting learning experience is when*  
21 *they actively, you know, work through examples that are at the right level for them, but they’re*  
22 *still a little guided”* (participant #3). Finally, four participants expressed the idea that students  
23  
24 could learn independently outside of the classroom, whereas one participant stated the opposite,  
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26 suggesting that students could not learn outside of the classroom.  
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37 *Beliefs about Content.* Beliefs about Content fell into three categories: selection of content to  
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39 prepare students for their future ( $n = 13$ ), the main goal was student understanding not content  
40  
41 coverage ( $n = 11$ ), and curriculum was a fixed agenda ( $n = 5$ ). The unique individual beliefs  
42  
43 under these three categories are presented in Table 2.  
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47 The most prevalent belief under the first category was the idea of the importance of selecting  
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49 content that will help students recognize the real-world applications of what they learn ( $n = 9$ ).  
50  
51 This belief is evident in the response of participant #13: *“What I’m trying to teach my students is,*  
52 *given that knowledge, how can we apply them [sic] in real problems? How can we take that*  
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3 *knowledge and solve a problem that we face in science?”* A related belief of the importance of  
4 incorporating scientific literature/authentic content was expressed by 6 faculty in this study.  
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7 Consider the quote from participant #16, who expressed a belief that exposing students to  
8 scientific literature prepares them for their future research activity: *“I actually assigned one*  
9 *paper for each student. So I am kind of training them for a lab grade. Many of them have no idea*  
10 *what bioanalytics is, but I just give them a paper and my hope is they learn from it.”* Other less  
11 prevalent beliefs under this category included ideas such as the importance of exposing students  
12 to a broad range of topics ( $n = 2$ ) to give them a “big picture” of the field, the importance of  
13 using examples that would help students remember the material ( $n = 2$ ), and selecting content  
14 that would increase student interest towards the subject ( $n = 1$ ).  
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26 The second category captures beliefs that communicate that the main goal of instruction was  
27 student understanding and not just content coverage ( $n = 11$ ). The most prevalent belief under  
28 this category was the idea that in order to help students acquire deep understanding of the  
29 subject, the instructor needed to spend more time teaching about discipline’s foundational  
30 concepts ( $n = 9$ ). This belief was best embodied in participant #18 response: *“There are a lot of*  
31 *things to talk about... exposing students to what is going on is great. But what particular parts of*  
32 *that class do you need to be able to move on... like what is truly foundational. And if everyone*  
33 *understands foundational and has a good, you know, I guess a level playing field to start at,*  
34 *that’s more important than just exposing them to everything that could be taught for example in*  
35 *organic chemistry.”* Seven faculty expressed another belief that was in the same vein as the  
36 belief above - the idea that introducing too much content was bad for students. These participants  
37 justified this belief by explaining that covering too much information made students feel  
38 overwhelmed and, despite an instructor’s good intentions, they did not retain much of that  
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3 material. This was evident in the response of participant #2, who stated: “*My first philosophy is*  
4 *to teach much less, but go in much greater depth... I think that there is a mistake with how much*  
5 *material is expected [to be covered]. I think you’re setting them up for failure. Even the ones that*  
6 *don’t fail don’t remember any of it when they walk out of the door.*” These participants believed  
7  
8 that covering less material more thoroughly promoted student conceptual understanding. The  
9  
10 final belief under this category was the idea that curriculum was a flexible agenda. This belief  
11  
12 was expressed by three participants who viewed curriculum as interactive and were willing to  
13  
14 alter their plan of content coverage to ensure meaning making on the part of students: “*After the*  
15 *workshop [CSC NFW] I do see the value in them understanding a topic. And so if we go a little*  
16 *over on a particular topic, I think it’s important that I address their questions and that they do*  
17 *understand the material that we are talking about before we move on*” (participant #8).  
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29 The final category under this theme captured beliefs that suggest that curriculum was a fixed  
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31 agenda ( $n = 5$ ). Participants who shared this belief stated that they did not alter the pace of  
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33 content coverage regardless of their students’ understanding. One participant justified this belief  
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35 by stating that she could not deviate from her syllabus because she needed to prepare her  
36  
37 students for the ACS exam which tests them on a broad range of topics. Four other participants  
38  
39 suggested that it is critical to cover everything to equip students for future courses: “*They will*  
40 *continue through Gen Chem I and Gen Chem II and if I don’t cover something, they will have*  
41 *[sic] trouble. I think we have to cover all of the course*” (participant #6). A similar idea was  
42  
43 expressed by participant #10: “*So I made a schedule at the beginning of the semester and I just*  
44 *stuck to it for better or worse. I do feel like there’s this mandatory list of topics that I at least*  
45 *have to touch on and so I can’t get myself slowed down by things that are just more*  
46 *complicated.*”  
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3 Once themes, categories, and codes were identified, participants' responses were analyzed  
4 based on their demographic parameters: sex, years of teaching, and course level taught. No  
5  
6 patterns were identified in this analysis (likely due to the small sample size).  
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### 9 10 *Types of Belief Systems*

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12 While it is valuable to detect themes *via* constant comparative analysis to characterize  
13 teaching beliefs of faculty, some key patterns might not be readily apparent to human coders, but  
14 are easily discovered when quantitative methods are used (Guest & McLellan, 2003; Macia,  
15 2015). To further explore patterns in the belief systems of our research participants, an  
16  
17 agglomerative hierarchical cluster analysis was conducted to identify groupings of faculty within  
18  
19 the sample. Cluster analysis has been and can be appropriately implemented in qualitative studies  
20  
21 so long as they are done in exploratory (versus predictive) ways (Guest & McLellan, 2003;  
22  
23 Macia, 2015). This allowed us to make discoveries based on combinations of multiple variables  
24  
25 and provided more insight than qualitative analysis alone. Although it is possible to classify  
26  
27 faculty based upon the overall profile of their beliefs about teaching and learning without using  
28  
29 quantitative approaches, the use of cluster analysis provided more rigor when analyzing  
30  
31 similarities and differences in the patterns of the belief profiles of our participants. The cluster  
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33 analysis was performed based on the previously identified codes under Beliefs about Students,  
34  
35 Beliefs about How Students Learn, and Beliefs about Content. Using this approach, both a 3- and  
36  
37 4-cluster solutions were found as supported by the scree plot. The cluster analysis was conducted  
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39 using different measures of similarity (complete-linkage, centroid-linkage, and Ward's methods)  
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41 and the same 3- and 4-cluster solutions were obtained. This indicated the stability of each of the  
42  
43 obtained cluster solutions. Additionally, to further ensure stability of the cluster solutions, the  
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45 cluster analysis was replicated several (7) additional times, every time mixing the order in which  
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the objects existed in the database (Brandriet & Bretz, 2014; Harshman, Yeziarski, & Nielsen, 2017). The same 3 and 4-cluster solutions were obtained every time. Finally, the 3- and 4-cluster solutions were carefully examined by the first and fifth authors. The 4-cluster solution was chosen as it allowed for description of the most homogeneous profiles of beliefs and interpretation of unique characteristics of each individual cluster (a dendrogram illustrating the results of the analysis can be found in the supplementary information, Figure S1). Note that two participants (#5 and #7) were excluded from the cluster analysis as outliers because each expressed only 1 belief about teaching and learning, whereas the rest of the participants expressed, on average, 7 beliefs (lowest observation equaled to 4 unique beliefs, whereas the highest observation equaled to 11). Shown in Table 3 are the prominent features of each cluster. Comparative demographics for each cluster can be found in the supplementary materials (Table S2). Below, is a description of the patterns in the belief profiles of each cluster across the three themes: Beliefs about Students, Beliefs about How Students Learn, and Beliefs about Content. With the limited sample size, the cluster solution was used to examine the data in a different way to maximize findings; we do not claim that these clusters will be observed in the broader assistant professor population.

Table 3 – Patterns in the belief profiles of each cluster.

<b>Cluster Label</b>	<b>Beliefs about Students</b>	<b>Beliefs about How Students Learn</b>	<b>Beliefs about Content</b>
1. <i>Student-centered &amp; consistent</i> ( $n = 7$ )	<ul style="list-style-type: none"> <li>Students possess different ability to grasp the material, but with instructor's help they can get better (<math>n = 5</math>)</li> </ul>	<ul style="list-style-type: none"> <li>Students can learn from each other (<math>n = 7</math>)</li> <li>Students learn better by doing/thinking, not listening (<math>n = 5</math>)</li> </ul>	<ul style="list-style-type: none"> <li>Incorporate literature or authentic content (<math>n = 4</math>)</li> <li>Teach about real-world applications of what students learn (<math>n = 5</math>)</li> <li>The focus is on few foundational concepts that students will use in future (<math>n = 5</math>)</li> <li>Too much content is bad (<math>n = 4</math>)</li> </ul>

2. <i>Transitional &amp; consistent</i> ( <i>n</i> = 3)	<ul style="list-style-type: none"> <li>• Students put in different level of effort (<i>n</i> = 2)</li> </ul>	<ul style="list-style-type: none"> <li>• Students learn by listening to the instructor (<i>n</i> = 2)</li> <li>• Students learn by paying attention (<i>n</i> = 3)</li> <li>• Students can learn from each other (<i>n</i> = 3)</li> </ul>	<ul style="list-style-type: none"> <li>• Students need exposure to a broad variety of topics (<i>n</i> = 2)</li> </ul>
3. <i>Instructor-centered &amp; inconsistent</i> ( <i>n</i> = 3)	<ul style="list-style-type: none"> <li>• Students need to assume responsibility for their learning (<i>n</i> = 3)</li> </ul>	<ul style="list-style-type: none"> <li>• Students learn better by doing or thinking, not listening (<i>n</i> = 2)</li> <li>• Students learn by listening to the instructor (<i>n</i> = 2)</li> <li>• Students learn when making connections between concepts (<i>n</i> = 2)</li> </ul>	<ul style="list-style-type: none"> <li>• Depth promotes conceptual understanding (<i>n</i> = 2)</li> <li>• Curriculum is a fixed agenda (<i>n</i> = 2)</li> </ul>
4. <i>Limited number of beliefs</i> ( <i>n</i> = 4)	<ul style="list-style-type: none"> <li>• Students possess different ability to grasp the material, but instructor doesn't aim to reach all students (<i>n</i> = 2)</li> </ul>	<ul style="list-style-type: none"> <li>• Students learn when making connections between concepts (<i>n</i> = 2)</li> <li>• Students learn when being conceptually engaged (<i>n</i> = 2)</li> </ul>	<ul style="list-style-type: none"> <li>• Teach about real world applications of what students learn (<i>n</i> = 4)</li> </ul>

*Cluster 1: Student-centered and consistent beliefs (n = 7).* Cluster 1 was represented by both males and females, with a range of teaching experience, some teaching graduate courses and others teaching undergraduate courses. In respect to the Beliefs about Students, faculty in this cluster showed growth mindset beliefs, stating that students possess different abilities to grasp the material, but with instructor's help they could improve. When it comes to the Beliefs about Content, most faculty discussed the importance of incorporating literature or authentic content, as well as real-world application examples of what students learn. They also emphasized that teaching too much material led to memorization and, when selecting content to teach, the focus should have been on foundational concepts that are critical for students' success in future courses and research. Finally, in respect to the Beliefs about How Students Learn, all noted that students could learn from each other and most mentioned that students learn better by doing/thinking, instead of listening. No faculty in this cluster said that students learned best when listening to the instructor. Thus, this cluster was assigned the label of "Student-centered and consistent beliefs."

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3        *Cluster 2: Transitional and consistent beliefs (n = 3).* Cluster 2 was represented by males  
4 only who teach graduate courses, with a range of teaching experience. In respect to the Beliefs  
5 about Students, faculty stated that different students put in different amounts of effort. When it  
6 comes to the Beliefs about Content, participants expressed that students needed exposure to a  
7 broad variety of topics. Finally, in respect to the Beliefs about How Students Learn, all said that  
8 students learned by paying attention and from each other, but also most said that students learned  
9 by listening to the instructor. Thus, this cluster was assigned the label of “Transitional and  
10 consistent beliefs.”  
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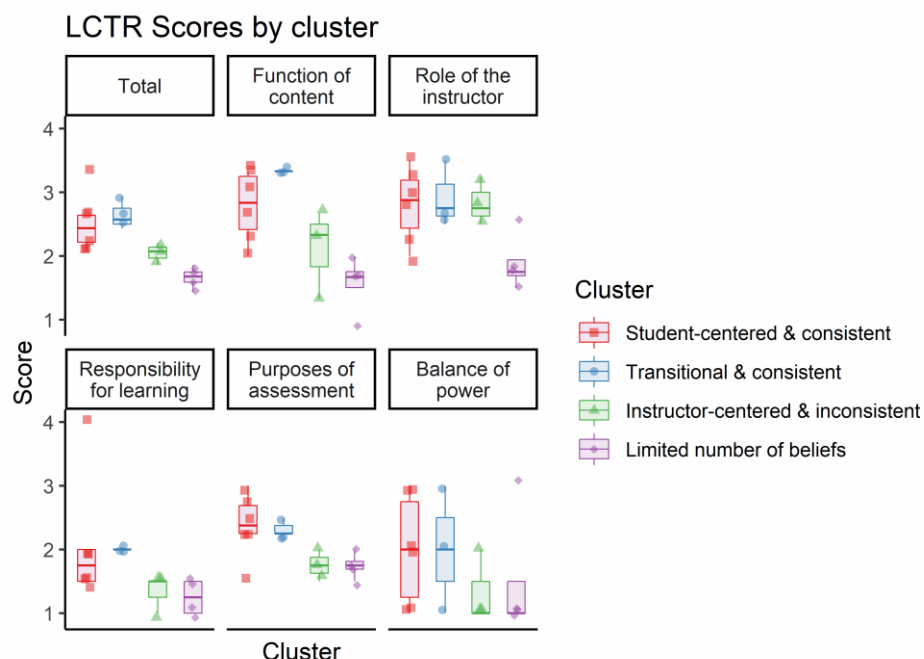
21        *Cluster 3: Instructor-centered and inconsistent beliefs (n = 3).* Cluster 3 was represented by  
22 males only, with a range of teaching experience, some teaching graduate courses and others  
23 teaching undergraduate courses. In respect to the Beliefs about Students, all participants in this  
24 cluster stated that students need to assume responsibility for their learning. When it comes to the  
25 Beliefs about How Students Learn, the participants showed contradicting beliefs – stating that  
26 students learned better by doing/thinking instead of listening, but at the same time noting that  
27 students learned best when listening to the instructor. No participants stated that students could  
28 learn from each other. Finally, in respect to the Beliefs about Content, the faculty yet again  
29 demonstrated contradicting beliefs. Even though they believed that depth promoted conceptual  
30 understanding, they saw curriculum as a fixed agenda, meaning that they did not alter the pace of  
31 content coverage regardless of their students’ understanding. Therefore, the label assigned to this  
32 cluster was “Instructor-centered and inconsistent beliefs.”  
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49        *Cluster 4: Limited number of beliefs (n = 4).* Cluster 4 was represented by females only, with  
50 a range of teaching experience, most teaching graduate. On average, participants in this cluster  
51 expressed 5 unique beliefs about teaching and learning, in comparison to an average of 8 unique  
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beliefs expressed by participants in all other clusters. For this reason, there were very few noticeable patterns in the beliefs' profile of this cluster. When it comes to the Beliefs about Students, half of the participants in this cluster expressed fixed mindset beliefs, as they noted that students possessed different abilities to grasp the material and there was nothing that the instructor could do to help students grow in their conceptual understanding. No other patterns were observed within the theme of the Beliefs about Students. In respect to the Beliefs about How Students Learn, half of the participants mentioned that students learned when making connections between concepts and when being intellectually engaged with the material. Finally, when it comes to the Beliefs about Content, all participants in this cluster discussed the importance of teaching about real-world applications of what students learned. Thus, due to the limited number of patterns in the beliefs' profile of this cluster, the label assigned to it was "Limited number of beliefs."

### *Relationship between Belief Systems and Instructional Practices*

Figure 2 – Box plots illustrating total LCTR scores for each cluster, as well as the scores for each cluster across the five dimensions of the LCTR.



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3 LCTR scores for participants in each cluster are illustrated in Figure 2. As can be seen in  
4 Figure 2 under “total,” participants in Cluster 1 (student-centered and consistent beliefs) and  
5 Cluster 2 (transitional and consistent beliefs) performed similarly on the LCTR (both obtained an  
6 average of about 2.5 points on the LCTR 1-4 scale). This mid-scale average signified that even  
7 though participants in Cluster 1 expressed more student-centered beliefs, they were not able to  
8 fully translate their vision and beliefs into their classrooms. Participants in Cluster 3 (instructor-  
9 centered and inconsistent beliefs) scored an average of 2 points on the LCTR scale, whereas  
10 participants in Cluster 4 (limited number of beliefs) obtained the lowest average score of 1.7  
11 points. This suggests an alignment between lower number of beliefs about teaching and learning  
12 and more instructor-centered practices in the classroom.  
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26 To gain additional insights as to why participants in different clusters scored the way they did  
27 on the LCTR, we analyzed distributions of clusters’ scores across the five dimensions of the  
28 LCTR (Figure 2). As can be seen from Figure 2, all four clusters showed different performance  
29 on dimension I – “the function of content,” with Cluster 2 participants scoring the highest  
30 indicating that they placed the largest emphasis on using content to help students acquire an in-  
31 depth understanding of the material and develop critical thinking skills. Figure 2 also illustrates  
32 that Clusters 1 and 2 outperformed Clusters 3 and 4 on dimension III – “the responsibility for  
33 learning,” dimension IV – “the purposes and processes of student assessment,” and dimension V  
34 – “the balance of power.” Thus, in comparison to Clusters 3 and 4, participants in Clusters 1 and  
35 2 used higher number of formative assessments, allowed for more flexibility of course policies,  
36 and set student expectations that enabled the responsibility for learning to be shared between the  
37 instructor and students. Finally, Clusters 1, 2, and 3 outperformed Cluster 4 on dimension II –  
38 “the role of the instructor.” This suggests that participants in Cluster 4 did not utilize a variety of  
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3 teaching techniques in their classrooms, making lecture their chief method of teaching.

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5 Additionally, participants in this cluster failed to align the learning goals for their course with the  
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7 assessment methods used to gauge student attainment of these goals.  
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### 10 **Conclusions and Discussion**

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12 This study sought to identify beliefs about teaching and learning of assistant chemistry  
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14 professors from research-intensive institutions, as well as the relationship between their beliefs  
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16 and instructional practices. Three themes describing instructors' beliefs were identified: Beliefs  
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18 about Students, Beliefs about How Students Learn, and Beliefs about Content.  
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22 The most commonly discussed idea under Beliefs about Students, was the belief that  
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24 different students were willing to put in different levels of effort (i.e., some work harder than  
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26 others) and that different students possessed different abilities to grasp the material (i.e., not all  
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28 students are equally capable). Faculty who expressed these ideas emphasized the distinction  
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30 between “good students” and “poor students” and expressed a range of beliefs along the fixed-to-  
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32 growth mindset continuum (Yeager & Dweck, 2012). Some stated that with help students could  
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34 get better and others explained that there was nothing that the instructor could do to help the  
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36 “poor students.” Presence of beliefs that are in congruence with the fixed theory of intelligence is  
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38 problematic as it has been previously shown that instructors with a more fixed mindset tend to  
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40 implement fewer active-learning strategies and are resistant to change (Aragón, Eddy, &  
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42 Graham, 2018). Similar findings were previously described by Padilla and Garritz (2015) who  
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44 reported that faculty from universities in Mexico also distinguished between “good” and “bad”  
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46 students when interviewed about their teaching. Prawat (1992, p. 363) cautioned that teachers  
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48 who place a strong focus on student individual differences are more driven towards “mindless  
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50 eclecticism in their instructional style,” where the focus is solely on the use of multiple teaching  
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3 methods to accommodate the needs of different students, instead of on careful selection of  
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5 content to allow for student thinking and sense-making.  
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8 In respect to the Beliefs about How Students Learn, faculty in this study expressed multiple  
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10 productive beliefs such as students were “able to learn from each other,” students learned “when  
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12 being conceptually engaged,” and “when making connections between concepts.” These findings  
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14 resonate with the work of Hora (2014), who also identified that science faculty beliefs about  
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16 student learning include ideas that learning is best facilitated through active, hands-on  
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18 engagement with the material and through active construction of understanding. Hora also  
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20 reported that faculty believe that students learn through repeated exposure to a topic/idea, as well  
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22 as through osmosis – by being in the presence of and listening to an expert; both of these ideas  
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24 have also been expressed by chemistry faculty in this study. Similarly, Gess-Newsome and  
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26 colleagues (Gess-Newsome *et al.*, 2003) reported that science faculty in their study held beliefs  
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28 that represented opposite ends along the constructivist to teacher-centered continuum: some  
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30 arguing that learning is much more than the rote acquisition of knowledge, whereas others  
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32 advocating for the transmission model of learning, where instructor’s ability to “tell story well”  
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34 is equated with student learning. Finally, faculty in this study have also expressed the belief that  
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36 students learned “when paying attention.” Prawat (1992) argued that those who hold this belief  
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38 are in fact “naïve” constructivists, as they often equate activity with learning and see student  
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40 interest in the classroom both as a necessary *and* sufficient condition for learning.  
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47 The final theme identified was Beliefs about Content. Most of the beliefs under this theme  
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49 illustrated that faculty in this study valued student understanding and selected content that was  
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51 useful to prepare students for their future research activity/careers. Multiple beliefs under this  
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53 theme were in congruence with those identified by Schultz and colleagues (Schultz *et al.*, 2018):  
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3 faculty value content with a focus “on the big picture,” “on fundamentals,” “on making  
4 connections between topics,” and “on real world applications.” A few faculty in our study,  
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6 however, also expressed a belief that “curriculum is a fixed agenda” – an idea previously  
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8 identified and discussed by Prawat (1992), as well as Padilla and Garritz (2015). The participants  
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10 who shared this belief stated that they did not alter the pace of content coverage regardless of  
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12 their students’ understanding.  
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17 Overall, the sophistication of beliefs of assistant chemistry faculty was somewhat superficial.  
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19 Participants expressed a range of ideas, from less productive to more productive; however, most  
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21 of the articulated beliefs lacked in depth. Thus, when discussing how students learn, participants’  
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23 explanations featured separate fragments rather than integrated structures one might call  
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25 “theories of learning” (e.g., constructivism, Ausubel and Novak’s theory of meaningful learning,  
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27 knowledge construction as integration of multiple types of learning) (Bretz, 2001; National  
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29 Academies of Sciences, Engineering, and Medicine, 2018; Novak, 1993).  
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34 Since no patterns were identified when comparing beliefs of faculty across different  
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36 demographic parameters (sex, years of teaching experience, and course level taught), an  
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38 agglomerative hierarchical cluster analysis was conducted to classify faculty based upon the  
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40 overall profile of their beliefs about teaching and learning. The analysis clustered faculty with  
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42 student-centered and consistent beliefs (Cluster 1), with transitional and consistent beliefs  
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44 (Cluster 2), with instructor-centered and inconsistent beliefs (Cluster 3), and those who  
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46 elaborated least on their teaching (Cluster 4). Although this study explored belief systems of a  
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48 fairly homogeneous sample of participants, there was a noticeable variation in the sophistication  
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50 of faculty’s beliefs. According to the Teacher-Centered Systemic Reform Model, past  
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52 experiences as students or contextual factors (e.g., cultural, school, and classroom contexts)  
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3 could explain this variability (Gess-Newsome *et al.*, 2003). Indeed, six of the faculty  
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5 spontaneously shared that their beliefs were anchored in their prior experiences as students.  
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8 In contrast to previous research (Addy & Blanchard, 2010; Douglas *et al.*, 2016; Şen & Sari,  
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10 2018), we did not identify a full alignment or misalignment between beliefs and practices.  
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12 Beliefs were generally correlated with practices, with beliefs being more advanced than  
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14 practices. Analysis of participants' instructional practices revealed that participants with student-  
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16 centered (Cluster 1) and transitional (Cluster 2) beliefs performed similarly on the LCTR and  
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18 outperformed faculty with instructor-centered beliefs (Cluster 3) and those who expressed  
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20 limited number of beliefs (Cluster 4). In fact, Cluster 4 obtained the lowest score on the LCTR  
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22 scale, which suggests that those who were least articulate about their teaching relied mostly on  
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24 instructor-centered strategies in the classroom. A deeper analysis into clusters' performance  
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26 across the different dimensions of the LCTR supported this conclusion. In comparison to the  
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28 other clusters, Cluster 4 participants did not utilize a variety of teaching techniques in their  
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30 classrooms, making lecture their chief method of teaching. Cluster 1 also displayed interesting  
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32 results, by showing difficulties in enacting beliefs. Although faculty in this cluster held student-  
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34 centered beliefs, they received only moderate scores on the LCTR, which suggested some  
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36 misalignment between their beliefs and practices. Beliefs of participants in other clusters were  
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38 somewhat aligned with their practices as characterized with the LCTR. These results highlight  
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40 the need for instructional reform facilitators to recognize the diversity of beliefs present within a  
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42 somewhat homogeneous group of instructors and differentiate the learning experience  
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44 accordingly. For example, the Teacher-Centered Systemic Reform Model would suggest that  
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46 helping faculty in Cluster 1 recognize the dissonance between their beliefs and instructional  
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48 practices could be fruitful in leading them to change their practices (Gess-Newsome *et al.*, 2003).  
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3 On the other hand, this approach would not prove effective for faculty in Cluster 2 and 3 since  
4 their beliefs and practices are well-aligned and dissatisfaction would not be established.  
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### 7 **Limitations**

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10 While this study shed light on the beliefs about teaching and learning of assistant chemistry  
11 faculty from research-intensive institutions, there are some key limitations. First and foremost,  
12 the small sample size ( $N = 19$ ) as well as the self-selection bias of respondents do not allow for  
13 generalizability of findings. Although the diversity of the participants minimizes this concern,  
14 the authors do not make any generalizability claims. In addition, our study participants were  
15 recruited while participating in the CSC New Faculty Workshop. Although this workshop did not  
16 aim to directly encourage faculty to reflect on their beliefs about teaching and learning, it could  
17 have had an indirect impact on our participants' beliefs.  
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28 The small sample size is also problematic for using cluster analysis. However, cluster  
29 analysis was not utilized in a predictive manner. The authors used cluster analysis solely in an  
30 exploratory fashion, to allow for a deeper qualitative examination of patterns in the beliefs'  
31 systems of the research participants. At the same time, some (Guest & Mclellan, 2003; Macia,  
32 2015) argue that cluster analysis is "ideal for most qualitative data" since, unlike other statistical  
33 methods, cluster analysis does not find generalizable characteristics; instead, it assists in ordering  
34 the available data into clusters. It is suggested that cluster analysis can be both a useful and a  
35 powerful tool in qualitative data analysis, as long as the researchers use rigor when developing  
36 and applying codes, as well as perform adequate manipulation of data to make it suitable for  
37 cluster analysis (Guest & Mclellan, 2003; Macia, 2015). In this study, we took measures to  
38 satisfy these requirements for the adequate application of cluster analysis to qualitative data.  
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3 Beliefs can be only inferred from what people say. They cannot be directly measured or  
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5 observed. If a participant holds a belief, but does not vocalize it, it is impossible to capture this  
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7 specific belief. Therefore, it is possible that we have not detected all of the beliefs about teaching  
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9 and learning held by our research participants. An open-ended interview protocol was used to  
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11 allow for follow-up questions and additional probing to reduce the number of undetected beliefs.  
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13 It is also possible that given a longer time for the interview and an even higher degree of  
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15 probing, the faculty might have expressed a more intricate system of beliefs.  
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19 Finally, two different interviewers collected the data which could result in inconsistencies in  
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21 how the interviews were conducted. Measures were taken to minimize this limitation - prior to  
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23 interviewing the final six participants in Fall 2018, the first author listened through multiple  
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25 interviews conducted by the third author in Fall 2016 and Spring 2017 to maintain similar level  
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27 of probing.  
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### 31 **Implications and Future Work**

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33 Knowledge of instructors' thinking can inform faculty professional development initiatives to  
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35 engage faculty to reflect on the beliefs that drive their classroom practices. Of importance is to  
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37 note that the work herein supports the notion that beliefs are very diverse and do not fall under  
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39 the limiting dichotomy of teacher-centered versus student-centered. The variation of  
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41 sophistication of faculty's beliefs indicates that faculty professional development experiences  
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43 need to be tailored towards providing its participants with more individualized support. In  
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45 addition, future efforts need to be directed toward identifying channels to challenge faculty to  
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47 become more self-aware of their beliefs about teaching and learning, to reflect on their teaching,  
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49 and to identify any disconnect between their teaching beliefs and instructional practices. It is also  
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51 critical to push faculty to reflect on the potential barriers for enactment of their beliefs in their  
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3 classrooms, with the aim of providing faculty with resources and support to overcome these  
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5 barriers.

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8 To gain deeper, more generalizable insights, future research should aim to reproduce this  
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10 study with a larger sample of faculty. Additionally, besides monitoring the relationship between  
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12 faculty teaching beliefs and instructional practices, more research is needed to understand the  
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14 impact of these beliefs and practices on student cognitive and affective outcomes. In particular, it  
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16 is important to discern whether there is a relationship between higher scores on the LCTR rubric  
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18 when analyzing faculty's classroom practices (i.e., faculty from the 'student-centered &  
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20 consistent cluster' and 'transitional & consistent cluster') and their students' conceptual  
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22 understanding and/or skills acquisition.  
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27 Finally, additional longitudinal research is warranted to identify the advancement of faculty  
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29 beliefs about teaching and learning over time. Since participants in this study were interviewed  
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31 after participating in the CSC NFW, it is interesting to identify whether any short-term impacts  
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33 of the workshop have diminished/increased/stayed constant. Previous research, that captured  
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35 CSC NFW participants' beliefs *via* surveys, reported that a short-term impact was observed after  
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37 the program as participants' beliefs became more student-centered. However, the observed gain  
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39 diminished a year later (Stains, Pilarz, & Chakraverty, 2015). Luft and Roehrig (2007) explained  
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41 that beginning faculty beliefs are more likely to change than those of their more experienced  
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43 colleagues. Therefore, future longitudinal research is needed to provide additional evidence on  
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45 the development of beliefs of novice faculty.  
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53  
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### Supplementary Information

Table S1 – Descriptive demographics for each participant.

<b>Demographic Variables</b>	<b>Faculty, <i>n</i></b>	<b>Faculty, #</b>
<b>Sex</b>		
Female	10	5, 7, 8, 9, 11, 12, 13, 15, 16, 19
Male	9	1, 2, 3, 4, 6, 10, 14, 17, 18
<b>Corse level taught</b>		
Graduate	10	1, 4, 6, 8, 11, 14, 15, 16, 17, 18
Undergraduate	9	2, 3, 5, 7, 9, 10, 12, 13, 19
<b>Year teaching</b>		
First	8	4, 10, 11, 14, 15, 16, 17, 18
Second	5	5, 6, 8, 12, 19
Third	3	7, 9, 13
Fifth	3	1, 2, 3

Table S2 – Modified TBI protocol used in this study.

1. What is your role in the classroom?
2. How do you think students successfully learn in your classroom?
3. How do you maximize student learning in your classroom?
4. How do you decide what to teach and what not to teach?
5. How do you decide when to move onto a new topic?
6. How do you know when students understand?
7. What are your main strengths as a teacher?
8. What are some areas of your teaching that you would like to improve?
9. Which scenario is worse: getting through all of the topics while only a minority of students understand them or getting through only some of the topics while a majority of students understand them?

Note that the question “How do your students learn best?” of the original TBI protocol was excluded from the TBI protocol used in this study because during the pilot testing of the protocol with our research participants, we received redundant responses from this question and “How do you maximize student learning in your classroom?” Furthermore, we included three additional questions to capture our study participants’ perceptions of their own teaching (questions 7-9).

Table S3 – Descriptive demographics for each cluster.

<b>Demographic Variables</b>	<b>Cluster 1 <i>n</i> = 7</b>	<b>Cluster 2 <i>n</i> = 3</b>	<b>Cluster 3 <i>n</i> = 3</b>	<b>Cluster 4 <i>n</i> = 4</b>
<b>Sex</b>				
Female	4	0	0	4
Male	3	3	3	0
<b>Course level taught</b>				
Graduate	3	3	1	3
Undergraduate	4	0	2	1
<b>Year teaching</b>				
First	2	2	1	3
Second	3	0	1	0
Third	1	0	0	1
Fifth	1	1	1	0

Table S4 – Components of LCTR used to analyze classroom observations and course artifacts.

<b>Dimensions</b>	<b>Components</b>
I. The function of content	<ol style="list-style-type: none"> <li>In addition to building a knowledge base, the instructor uses content to help students understand why they need to learn the content for courses within or outside their major and for their future career.</li> <li>The instructor uses content to practice using scientific practices in the discipline or to solve authentic problems</li> <li>The instructor helps students acquire in-depth conceptual understanding of the content to facilitate deep learning and use of transferable skills</li> </ol>
II. The role of the instructor	<ol style="list-style-type: none"> <li>The instructor creates a supportive and success-oriented environment for learning and for accomplishment for all students through proactive, clear, and overt course-specific techniques</li> <li>The instructor uses diverse teaching strategies that promote the achievement of student learning</li> <li>The instructor develops and uses a variety of learning outcomes/goals</li> <li>The instructor aligns two essential components of a course: learning outcomes/goals and assessment methods in terms of content and consistent verbs representing the same cognitive processing demands/intellectual skills placed on the students</li> </ol>
III. The responsibility for learning	<ol style="list-style-type: none"> <li>The instructor sets student expectations, which enable the responsibility for learning to be shared between the instructor and the students</li> <li>The instructor fosters students' engagement in reflection and critical review of their learning through well-structured activities</li> </ol>
IV. The purposes and processes of student assessment	<ol style="list-style-type: none"> <li>The instructor uses formative assessment within the learning process</li> <li>The instructor promotes students to use peer-assessments</li> <li>The instructor allows the students to demonstrate mastery of the objectives and ability to learn from mistakes</li> <li>The instructor uses authentic assessments (e.g., research report, case study)</li> </ol>
V. The balance of power	<ol style="list-style-type: none"> <li>The instructor allows for some flexibility of course policies, assessment methods, learning methods, and deadlines or how students earn grades</li> </ol>

Figure S1 – Dendrogram illustrating the results of the agglomerative hierarchical cluster analysis.

