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Changes in teaching beliefs of early-career chemistry faculty: A longitudinal investigation

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Abstract

Literature at the secondary level has demonstrated a tight interconnectedness between one's beliefs about teaching and learning and one's instructional practices. Moreover, this research indicates that personal and contextual factors influence beliefs and that growth and changes in beliefs are most notable during the early years of one's teaching experience. Despite the substantial influence of teaching beliefs on educational decisions, very little research has been conducted at the post-secondary level in both characterizing and monitoring changes in beliefs over time of early-career faculty members. This study aims to fill this gap by investigating 1) the changes over two and half years in the beliefs of early-career chemistry professors in the United States, and 2) patterns between changes in beliefs and personal and contextual factors as defined in the Teacher-Centered Systemic Reform Model. Nine faculty were interviewed using the modified Luft and Roehrig's Teaching Beliefs Interview protocol in Fall 2016/Spring 2017 and then again in Spring 2019. Combination of constant-comparative analysis and cluster analysis were utilized to characterize faculty beliefs after each data collection cycle. Faculty also completed four surveys over the course of this longitudinal study. These surveys were analyzed to identify personal and contextual factors that could relate to changes in faculty beliefs over time. Overall, the participants expressed more unique beliefs about teaching and learning during the second interview. Despite this increase, the substance and the message of the beliefs remained fairly similar to the beliefs expressed during the first interview, which suggests that beliefs do not change as an artifact of teaching experience. Four of the faculty demonstrated a desirable shift to student-centered thinking, while three did not change and two shifted toward teacher-centered. Analysis of the survey data revealed that access and use of chemical education research journal and researchers, repeated opportunities to teach the same course, and

instructor's continued learning efforts with respect to teaching were more pronounced among faculty who shifted toward student-centered thinking.

Introduction

Teaching beliefs have been defined as “tacit, often unconsciously held assumptions about students, classrooms, and the academic material to be taught” (Kagan, 1992, p. 65). The empirical evidence presented in the educational literature, particularly at the secondary level, indicates that beliefs that instructors hold about teaching and learning affect their instructional practices (Dolphin & Tillotson, 2015; Enderle et al., 2014; Feyzioğlu, 2012; Gibbons et al., 2018, Pajares, 1992; Şen & Sarı, 2018; Southerland et al., 2016; Wong & Luft, 2015). Characterizing instructors’ beliefs, their connections to instructional practices and factors that influence them is thus critical to advancing instructional change.

Current studies on teaching beliefs, which have mostly been conducted at the secondary level (Fletcher & Luft, 2011; Luft et al., 2011; Wong & Luft, 2015), fall mainly into three categories: characterization of beliefs (Chapman & McConnell, 2018; Hora, 2014; Lee, 2019; Mavhunga & Rollnick, 2016; Pratt & Yezierski, 2019), measure of the impact of instructional reforms on participants’ beliefs (Czajka & McConnell, 2019; Lee, 2019; Mattheis & Jensen, 2014; Moore et al., 2015; Pelch & McConnell, 2016), and exploration of the relationship between beliefs and practice (Addy & Blanchard, 2010; Czajka & McConnell, 2016; Dolphin & Tillotson, 2015; Douglas et al., 2016; Popova et al., 2020; Şen & Sarı, 2018). Most studies aiming to characterize teaching beliefs place beliefs on the continuum from teacher-centered to student-centered. Teacher-centered beliefs generally reflect the idea that students learn from listening to an instructor teach (beliefs that support didactive mode of instruction), whereas student-centered beliefs reflect the ideas that students learn when conceptually engaged with the content and when interacting with their peers to construct understanding (beliefs that support active forms of instruction) (Luft & Roehrig, 2007). Transitional beliefs represent the midpoint along this continuum. Several of these studies have explored change in beliefs over time but through cross-sectional samples rather than following longitudinally the same group of instructors. This is likely due to the understandable difficulty associated with collecting and analyzing longitudinal data, but the absence of longitudinal data prevents knowledge generation about how instructors change over time.

Research has demonstrated the importance of characterizing the changes over time of the beliefs of novice or inexperienced instructors since these beliefs are still developing and more malleable than those of experienced instructors (Luft, 2001). For example, Wong and Luft (2015) followed 35 beginning secondary science instructors over the course of five years and they found that instructors with more student-centered beliefs were more likely to persist in teaching as their career. Two longitudinal studies demonstrated the influence of a lack of continuous professional development on new teachers' beliefs about teaching and learning. Luft and colleagues (Luft et al., 2011) followed 98 beginning secondary science teachers over the course of two years to investigate the changes in their beliefs, pedagogical content knowledge (PCK), and teaching practices after exposure to different professional development programs. They found that most of the teachers' beliefs were more student-centered during the first year, while they were provided on-going support by the professional development programs, but shifted toward more instructor-centered in the second year, during which no support was provided. Similarly, Fletcher and Luft (2011) followed five prospective secondary science instructors that participated in a university preparation program over the course of three years and found that their participants held more student-centered beliefs during the program, but shifted to instructor-centered thinking in their first year of teaching. To our knowledge, few studies have investigated changes in new STEM faculty members' beliefs about teaching and learning as they are gaining teaching experience.

Although one may assume that secondary teachers and faculty members hold similar beliefs, their experiences and working contexts are vastly different. For example, Fletcher and Luft (2011) emphasized that each participant in their study held a unique set of beliefs because beliefs are shaped by the individual experiences, backgrounds, and training of each educator. Moreover, several contemporary empirical models on instructional change, including the Interconnected Model of Instructor Professional Growth (Clarke & Hollingsworth, 2002) and the Teacher-Centered Systemic Reform Model (Gess-Newsome et al., 2003), highlight the influence of contextual factors (e.g., environment) on instructors' beliefs about teaching and learning. Characterizing changes in beliefs over time of new STEM faculty and factors that could have influenced these changes would be extremely valuable to identify support mechanisms and professional development programs that would help develop and sustain student-centered beliefs among new generations of faculty members. This study starts to address this need by answering the following research questions:

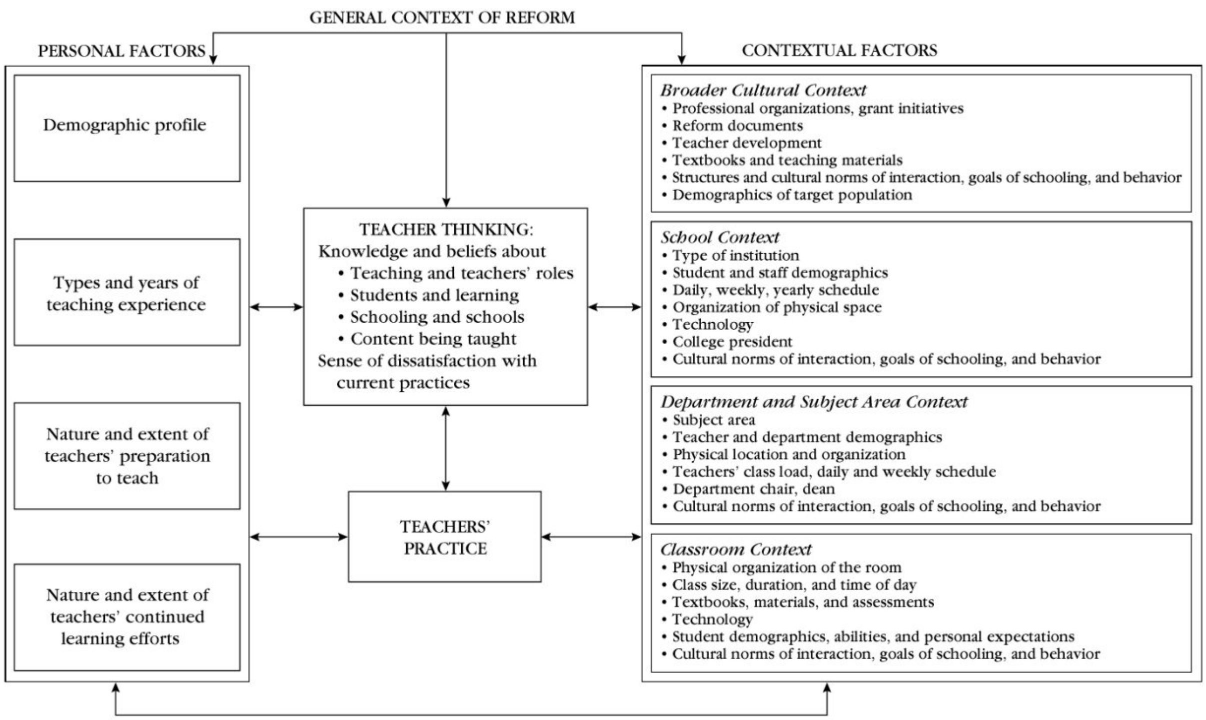
1. How do the teaching beliefs of early career chemistry faculty members change over time?
2. To what extent do personal and contextual factors relate to changes observed over time in a sample of early career chemistry faculty members' beliefs?

Theoretical Framework

The overall system of beliefs that an individual holds is composed of many beliefs that develop over time. Earlier beliefs in this network are held more strongly, are resistant to change, and have a great influence on the processing and recalling of the stored information, as they serve as a filter through which new phenomena is interpreted (Pajares, 1992). In contrast to knowledge, beliefs often lack an internal consistency with the overall system of beliefs that one holds because of their subjectivity. Beliefs are subjective by nature because they are based on evaluation, judgement, bias, and generalizations drawn from personal experiences. Despite this, some have argued that beliefs are much more influential than knowledge when explaining behavior (Nespor, 1987).

Models for instructional reforms have emphasized the roles that personal factors can have in shaping one's beliefs but also the influence of beliefs on instructional practices (Clarke & Hollingsworth, 2002; Gess-Newsome et al., 2003). In this study, we focus on the Teacher-Centered Systemic Reform Model (TCSR, Figure 1) because this model places instructor beliefs (along with instructor knowledge) at its core under the label teacher thinking. It connects beliefs to not only personal factors (i.e., demographic profile, types and years of teaching experience, nature and extent of instructors' preparation to teach, and nature and extent of instructors' continued learning efforts) and instructor's practices but also to contextual factors (i.e., cultural context, school context, department and subject area context, and classroom context). The TCSR Model was developed by Woodbury and Gess-Newsome (2002) from their synthesis of the perspectives on reform in secondary education research. The model illustrates "interdependent elements of reform" which reflects the view of education as a system (Woodbury and Newsome, 2002). Several factors (personal, contextual, teacher thinking, and practice) are interconnected in this model to explain the multi-faceted systemic nature of education and the need to consider these interconnected factors when a change/reform is to be implemented. One of the main assumptions of the TCSR model is that change in instructional practices will result in better student outcomes. As previous studies have shown (Andrews et al., 2011), adoption of new instructional practices does not always result in enhanced student outcomes since faculty often adapt the innovation to fit their context and in doing so remove critical elements that made the innovation effective (Stains & Vickrey, 2017).

Figure 1 – Teacher-Centered Systemic Reform model (TCSR). Reproduced with permission from Gess-Newsome et al., 2003



Methods

Data Collection and Sample

Thirteen assistant chemistry professors participated in semi-structured, think-aloud interviews (Drever, 1995; Patton, 2002) and provided surveys over the course of two and half years (IRB Number: 20151115802 EX). The timeline for data collection is presented in Figure 2.

Figure 2 – Timeline describing the collections of surveys and interviews for the participants involved in this study.

The first set of interviews was collected in Fall 2016 and Spring 2017. Faculty members were recruited while attending the Cottrell Scholars Collaborative New Faculty Workshop (CSC NFW, Baker et al., 2014). All faculty participants were from Master's and Doctoral Universities according to the Carnegie's classification (Center for Postsecondary Research). A code number was created for each participant to protect their identity. The modified Instructor Belief Interview (TBI) protocol was used to elicit their beliefs about teaching and learning (Luft & Roehrig, 2007). Although this interview protocol was developed within the K-12 context, it has been used in higher education contexts (Chapman & McConnell, 2018; Czajka & McConnell, 2019; Czajka & McConnell, 2016). The protocol was modified because two questions in the original protocol elicited redundant responses, "How do your students learn science best?" and "How do you maximize student learning in your classroom?" For this reason, we excluded the former question. Details pertaining to the first interview data collection procedures have been previously reported (Popova et al., 2020). What follows is a detailed description of the second interview data collection procedures which strongly resembles the first interview data collection process.

In Spring 2019, these thirteen chemistry professors were invited to participate in a second interview that utilized the same modified Instructor Belief Interview (TBI) protocol (the interview protocol can be found in the supplementary material). All but four (P1, P2, P3 and P13) of the original thirteen participants agreed to participate in the second interview. These nine faculty were located across eight different states in the US, spanning all four of the regional divisions recognized by the US Census Bureau (U.S. Department of Commence): 3 universities in the South, 3 in the West, 2 in the Northeast, and 1 in the Midwest. Because this population was geographically diverse, multimedia-based programs (e.g., Skype, Zoom) were used to interview the faculty participants. An audio recorder was used to capture the data. Demographic details for the sample are shown in Table 1. Note that chemistry course or level (undergraduate or graduate) taught by faculty members changed for four (P6, P8, P9, P11) of the participants going from the first to second interview (e.g., P6 taught an undergraduate biochemistry course in Fall 2016 and a graduate biochemistry course in Spring 2019). Each faculty received a $50 gift card for participating in the second interview.

Faculty members also completed several surveys (pre, post workshop, as well as 1- and 3-year following participation in the workshop). One of the goals of the surveys was to capture faculty characteristics within factors of the TCSR model; of particular interest for this study were the questions targeting personal and contextual factors as these could relate to the changes in beliefs over time (for survey items used in this study, see supplemental materials).

Table 1 – Descriptive demographics for the sample. Note that G stands for a graduate course and U stands for an undergraduate course

ID	Gender	First interview		Second interview	
		Year teaching	*Chemistry course*	*Year teaching*	*Chemistry course*
P4	M	First	Bioanalytical, G	Third	Bioanalytical, G
P5	F	Second	Inorganic, U	Fourth	Inorganic, U
P6	M	Second	Biochemistry, G	Fourth	Biochemistry, U
P7	F	Third	Biochemistry, U	Fifth	Biochemistry, U
P8	F	Second	Analytical, G	Fourth	Analytical, U
P9	F	Third	Inorganic, U	Fifth	General, U
P10	M	First	Biochemistry, U	Third	Biochemistry, U
P11	F	First	Organic, G	Third	Organic, U
P12	F	Second	Analytical, U	Fourth	Analytical, U

Data Analysis

Interviews

Analysis of the second interview data followed the same steps as the analysis of the first interview data previously described in details (Popova et al., 2020), but the general process will be outlined here. Once transcribed verbatim, the interviews were read to identify quotes that communicated beliefs about teaching and learning (i.e., not descriptions of *what* chemistry professors are doing in their classrooms, but explanations of *why* they are doing it). All of the identified quotes were uploaded to NVivo 12 to be stored, organized, and deductively coded (Bazeley & Jackson, 2013; Creswell, 2003; Patton, 2002) using a code book that captured faculty participants' Beliefs about Students, Beliefs about Content, and Beliefs about How Students Learn. This code book was developed while analyzing the first interview data from our faculty participants (Popova et al., 2020). Three coders used the rubric to code the first interview data and, after multiple debriefing sessions, they achieved a 100% interpretive convergence (Saldaña, 2013). The team coding, or what Saldaña describes as "analyst triangulation," ensured reliability and credibility of the results, as frequent debriefing sessions helped the researchers address any biases and assumptions brought to the interpretative analysis (Pandey & Patnaik, 2014; Saldaña, 2013). After ensuring a complete agreement on the collective coding of the first interview data, the first author independently coded the second interview data. Any beliefs previously not expressed during the first interviews were captured to augment the original code book. The first author met weekly with the second and fourth authors to discuss the process of coding (especially any differences between the first and second sets of interviews). The discussions during these periodic meetings helped further the confidence in the rigor of findings and establish credibility of the results (Saldaña, 2013). The final code book for the first and second interview data is shown in Table 2.

While it is informative to detect and contrast beliefs *via* constant comparative analysis, additional use of quantitative methods can enrich the evidence and enable research question one to be answered more deeply. Therefore, in order to characterize patterns across the different types of beliefs about teaching and learning expressed by our faculty participants, an agglomerative hierarchical cluster analysis was conducted. Following the same procedure as when performing the cluster analysis for the first interview data (Popova et al., 2020), the nine faculty who participated in the second interviews were clustered based on their Beliefs about Students, Beliefs about Content, and Beliefs about How Students Learn (capitalization indicates name of themes referred throughout the rest of the manuscript). By running a matrix coding query in NVivo, a table illustrating what beliefs were expressed by each participant was generated, in which “0” indicated absence of a belief and “1” indicated presence of a belief. This categorical, nominal data was uploaded to IBM SPSS 25 to perform the cluster analysis. The agglomerative procedure began with each participant representing an individual cluster and then successively merging clusters together until a hierarchy of nested groupings was created (Frades

& Matthiensen, 2010). Since faculty were classified solely on the patterns in their beliefs and elevation of scores across variables of interest was not applicable, Pearson's correlation similarity measure was selected to measure the association between the variables (Clatworthy et al., 2005; Wilks, 2014). Cluster analysis results for the first interview data have been previously reported (Popova et al., 2020) and results for the second interview data are shown below.

Surveys

Surveys collected information capturing faculty characteristics and institutional environments aligned with the personal and contextual factors within the TCSR Model. Personal factors examined included faculty sex, teaching experience, familiarity with evidence based instructional practices (EBIPs), and continued learning (seen as attendance in professional development). Contextual factors included institution, department, and course contexts (e.g., Carnegie classification, teaching load, type of course taught, and types of teaching-related resources available/accessed). Of note, only questions in the survey that had a minimum 50% response rate within each cluster were included in the analysis (questions that did not meet this threshold are provided in the supplementary material). Survey responses within these factors were compared across patterns identified from the interview data to explore any potential relations that may explain any changes seen in beliefs over time. Due to the small sample size, no inferential analyses were conducted and only qualitative comparisons were made.

Results

Changes in the Types of Beliefs about Teaching and Learning

Overall, participants expressed a higher number of beliefs about teaching and learning during the second interviews (Table 2). During the first interviews faculty articulated an average of 6 unique beliefs (lowest observation equaled to 1 unique belief, whereas the highest observation equaled to 10) while during the second interviews, they expressed an average of 9 unique beliefs (lowest observation equaled to 5 unique beliefs, whereas the highest observation equaled to 11). Figure 3 illustrates these changes for each faculty participant.

Table 2 – Themes, categories, and codes that capture beliefs of early-career chemistry faculty. Note that the total number of instances for each theme is greater than the number of faculty in this study ($N = 9$) because one participant could express multiple beliefs and, therefore, be assigned to multiple codes within one theme.

Theme I: Beliefs about Students

Category	Code/Belief	First	Second
Highlighting student differences	Different students put in different level of effort	2	6
	Different students possess different ability to grasp the material and the instructor does not aim to reach all students	2	1
	Different students possess different ability to grasp the material, but with help students can get better	1	3
	International students are reluctant to participate	1	0
	Non-major students are intimidated by chemistry	1	0
	Active learning is not uniformly beneficial for all students	0	2
General to all students	Students need to assume responsibility for their learning	2	5
	Humans have limited attention spans/working memory capacity	2	0
	Students like lecturing	0	2
	Students think they know more than they actually do	0	1
	Students lack productive study habits	0	1
	Students do not like active learning	0	1

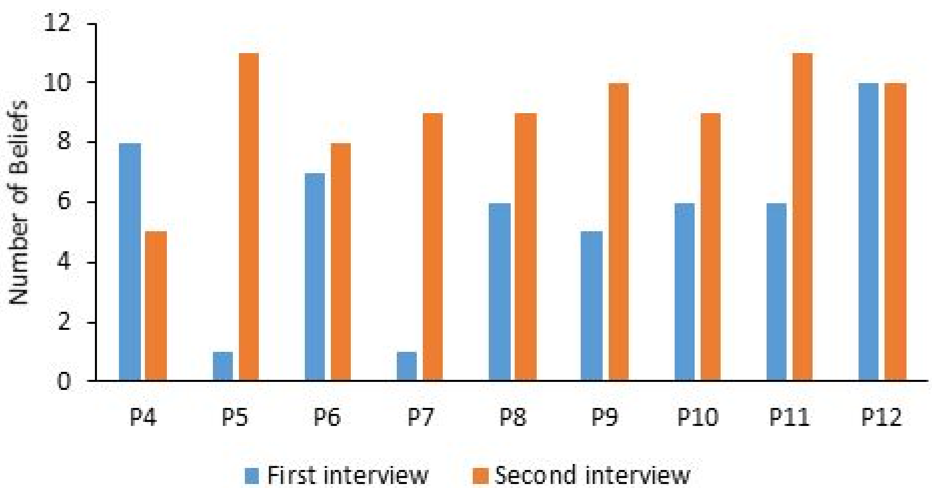
Theme II: Beliefs about How Students Learn

Category	Code/Belief	First	Second
Mechanisms through which learning occurs	Learn better by doing/thinking, not listening	5	3
	By listening to the instructor	2	4
	When making connections between concepts	2	1
	When applying their knowledge	2	2
	By paying attention	1	5
	By repetition	1	5
	When being conceptually engaged	1	4
	When being conceptually challenged	1	0
	When being reflective	0	2
	When actively taking notes	0	1
Context in which learning occurs	Can learn from each other	4	5
	Can learn outside of class	2	1
	Learn best with instructor's guidance	1	0
	Learn best in a positive classroom environment	0	1

Theme III: Beliefs about Content

Category	Code/Belief	First	Second
The goal is student understanding, not content coverage	Focus on foundational concepts	3	5
	Teaching too much content is bad for students	2	2
	Curriculum is a flexible agenda	1	3
Selection of content to prepare students for their future	Incorporating literature or authentic content	2	2
	Real-world applications of what students learn	2	6
	Exposing students to a broad range of topics	1	0
	Content that will make students more interested	1	5
Curriculum is a fixed agenda		3	3

Figure 3 – Number of beliefs about teaching and learning expressed by each participant during the first and second interviews



In general, faculty participants expressed similar beliefs in both interviews. When new beliefs were articulated in the second interviews, they were not prevalent. For example, several new, mostly idiosyncratic beliefs were expressed about students: "students like lecturing" (n = 2), "active learning is not uniformly beneficial for all students" (n = 2), "students think they know more than they actually do" (n = 1), "students lack productive study habits" (n = 1), and "students do not like active learning" (n = 1). Three new beliefs were also expressed about how students learn: students learn "when being reflective" (n = 2), "when actively taking notes" (n =1), and students "learn best in a positive classroom environment" (n = 1). No new beliefs were expressed about content.

In respect to the prevalence of the beliefs that were articulated during both the first and second interviews, few noticeable changes were observed for Beliefs about Students, Beliefs about How Students Learn, and Beliefs about Content (Table 2). In respect to Beliefs about Students, two beliefs from the first interviews were expressed more prominently in the second interviews: "different students put in different level of effort" (from n = 2 to n = 6) and "students need to assume responsibility for their learning" (from n = 2 to n = 5). During the first interviews, the following codes were the most prevalent under the category of "mechanisms through which learning occurs," which is a category under Beliefs about How Students Learn (Table 2): students learn better "by doing/thinking, not listening" (n = 5), "by listening to the instructor" (n = 2), "when making connections between concepts" (n = 2), and "when applying their knowledge" (n = 2). During the second interviews, however, the most prevalent beliefs under this category became "by paying attention" (n = 5), "by repetition" (n = 5), "when being conceptually engaged" (n = 4), and "by listening to the instructor" (n = 4). In respect to the Beliefs about Content, two beliefs that were not very prevalent during the first interviews were expressed with much greater frequency: teaching about "real-world applications of what students learn" (from n = 2 to n = 6) and selecting "content that will make students more interested" in the subject (from n = 1 to n = 5).

Types of Belief Systems in the Second Interviews

The cluster analysis was performed on the second interviews based on the identified codes under Beliefs about Students, Beliefs about How Students Learn, and Beliefs about Content. The analysis was conducted using Pearson's correlation similarity measure and the same cluster solution was obtained with Centroid Linkage and Ward's method, which suggests stability of the obtained cluster solution (a dendrogram illustrating the results of the analysis can be found in the supplementary information). The qualitative examination of 2-, 3-, and 4-cluster solutions to identify the most homogeneous profiles of beliefs supported a 2-cluster solution as the solution that offers a clear interpretation of unique characteristics of each individual cluster. Additionally, to further ensure stability of the cluster solution, the cluster analysis was replicated several (7) additional times, every time mixing the order in which the objects existed in the database (Brandriet & Bretz, 2014; Harshman et al., 2017). The same cluster solution was obtained every time. The cluster analysis was used to examine the data for some key patterns that might not be readily identified using qualitative techniques only. While plausible, we do not present evidence or claim that these groupings will be observed in the broader professor population.

Shown in Table 3 are the comparative demographics for the two clusters. Table 4 depicts the prominent features of each cluster. Below, is a description of the patterns in the belief profiles of the two identified clusters across the three themes: Beliefs about Students, Beliefs about How Students Learn, and Beliefs about Content.

Table 3 – Descriptive demographics for each cluster

Demographic Variables	**Cluster 1** *n* = 6	**Cluster 2** *n* = 3
Sex		
Female	4	2
Male	2	1
Course level taught		
Graduate	1	0
Undergraduate	5	3
Year teaching		
Third	1	2
Fourth	3	1
Fifth	2	0

Table 4 – Patterns in the belief profiles of each cluster

Cluster Label	Beliefs about Students	Beliefs about How Students Learn	Beliefs about Content
1. *Student-centered & consistent (n = 6)*	• Students possess different ability to grasp the material, but with help they can get better (n = 3)	• Students can learn from each other (n = 5)	• Teach about real-world applications of what students learn (n = 5) • Content that will make students more interested (n = 4)
2. *Instructor-centered & consistent (n = 3)*	• Students put in different level of effort (n = 3)	• Students learn by paying attention (n = 3) • Students learn by listening to the instructor (n = 3)	• Incorporate literature or authentic content (n = 2) • Curriculum is a fixed agenda (n = 2)

Cluster 1: Student-centered and consistent beliefs (n = 6). In respect to the Beliefs about Students, half of the faculty in this cluster (n = 3) showed growth mindset beliefs, stating that students possess different ability to grasp the material, but with help they can improve. For example, when explaining why he assigns students to work in groups, P6 explained: "*There is always a difference in proficiency. Some students catch things very quickly. Some students may take longer. So they kind of teach each other. Biochem is based on gen chem and organic chemistry concepts and not all of them are proficient in all of those concepts… When I get students to talk, some of them are better at organic and they will say - this is aldol condensation. Less proficient ones can ask why*." As is evident from this quote, P6 believes that students can teach each other and the "less proficient" students can improve in their understanding of concepts.

When it comes to the Beliefs about Content, most faculty in this cluster discussed the importance of connecting the content to students' lives either by incorporating content that will make students more interested in the subject (n = 4) or by including real-world applications of what students learn (n = 5). This is evident in the quote of P8: "*So my view is, hopefully if they see how this matters in medicine, and environmental science, and forensics, et cetera, they become more excited about it and want to really understand the techniques in the material better. Um, so a lot of examples that I try to give are related to those applications of the material.*"

Finally, in respect to the Beliefs about How Students Learn, most (n = 5) noted that students can learn from each other: "*Instructors tend to think that they are very useful when lecturing, but I don't think that's true. I think that students tend to learn what they need from each other*" (P8) and "*Students learn not only from me, but also from peers. For example, the final assignment is group presentations… Students do the peer evaluation, peer review, they give each other some feedback. And what I always say to the students – learn from your peers*" (P4). Thus, having considered the patterns in the beliefs across the three themes, this cluster was assigned the label "student-centered and consistent beliefs."

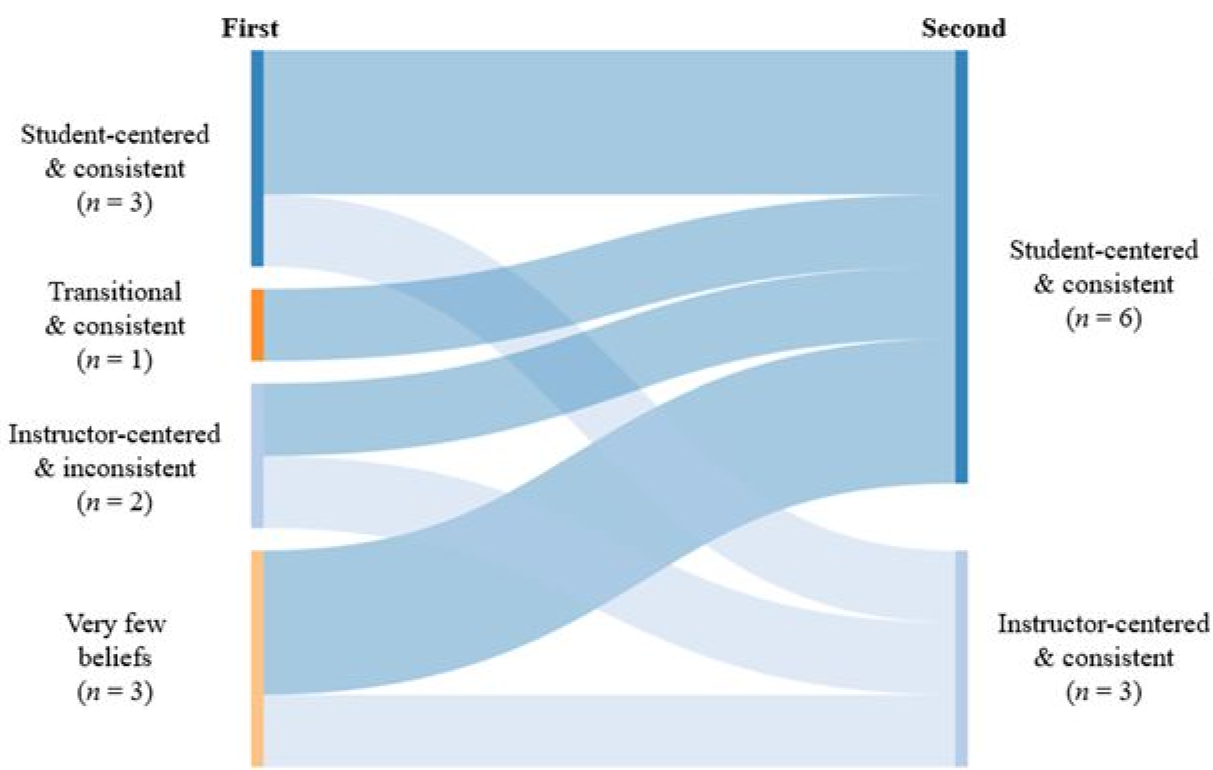
Cluster 2: Instructor-centered and consistent beliefs (n = 3). In respect to the Beliefs about Students, all of the participants (n = 3) in this cluster discussed the issue that different students put in different levels of effort. For example, faculty explained that some students come to class unprepared - they do not do the assigned homework. For this reason, when it comes to the Beliefs about How Students Learn, the participants in this cluster stated that students learn by paying attention in class (n = 3) and by listening to the instructor (n = 3), because when students come to class unprepared, lecture is the most effective approach to get them "on the same page." This is evident in the quote of P12: "*For some students, for example those who don't do the readings, who are lacking motivation, they're struggling in the active learning teaching style… I feel that when I give lectures a little bit more, even those who didn't do their homework, they* *didn't do the reading or watch those videos, they will still have a basic idea about how this instrument works*." P11 also discussed that students learn well from an authority figure: "*When they take this class, they don't have much organic chemistry background. So I think it's nice for them to actually have someone to be essentially authority figure and then tell them these are things that are, that we should learn in this class*."

In respect to the Beliefs about Content, the faculty emphasized the importance of incorporating literature or authentic content ($n = 2$). For example, P12 stated: "*Of course I will give them some other, uh, introductions about the modern techniques, for example some [*inaudible word*] and Raman spectroscopy, which are not covered in ACS, but uh, they're used a lot in research*." Finally, most faculty in this cluster ($n = 2$) saw curriculum as a fixed agenda, meaning that they would not alter the pace of content coverage: "*I won't skip any chapters, um, for this class because I think everything is important. Um, especially when you have a second semester to take, if you miss one chapter it's gonna probably cause some issues in second semester, um, or even down the line, in the class"* (P11). Having considered the patterns in the beliefs across the three themes and the fact that no participant stated that students can learn from each other (instead all believed that students learn best by paying attention and listening to the instructor), this cluster was assigned the label "instructor-centered and consistent beliefs."

Changes in the Types of Belief Systems Over Time

Cluster analysis of the first interview data grouped faculty into four distinct clusters (Figure 4). "Student-centered and consistent beliefs" cluster believed that students learn best by doing/thinking instead of listening and that students learn best from interactions with their peers. "Transitional and consistent beliefs" cluster believed that students learn best from both paying attention to the instructor and from interacting with each other. "Instructor-centered and inconsistent beliefs" cluster believed that students learn best by doing/thinking instead of listening. At the same time, they also believed that students learn best by listening to the instructor lecture. Additionally, faculty in this cluster believed that depth of content coverage promotes conceptual understanding, while simultaneously believing that curriculum is a fixed agenda. Since these instructors simultaneously held competing ideas, their beliefs were labeled as inconsistent. Finally, "limited number of beliefs cluster" expressed very few beliefs in comparison to the faculty in the other three clusters and there were no patterns in their beliefs to characterize them on the continuum from instructor- to student-centered (Popova et al., 2020). Figure 4 illustrates how participants changed in the cluster assignment from the first to second interview.

Figure 4 – Changes in cluster membership between the first and second interviews



As can be seen, after about two and a half years, some participants remained in their original clusters (i.e., P8 and P9 in the cluster of "student-centered beliefs" and P10 in the cluster of "instructor-centered beliefs"). Note that although when analyzing both the first and second interview data we identified a cluster of "instructor-centered beliefs", this cluster slightly changed over time. Participants who fell under this cluster in the first interviews expressed not only instructor-centered beliefs, but also contradicting beliefs (i.e., stating that students learn better by doing/thinking instead of listening, but at the same time noting that students learn best when listening to the instructor). No such inconsistencies were identified in the beliefs profile of this cluster when analyzing the data from the second interviews.

All faculty who were initially in the cluster of "limited number of beliefs" shifted to other clusters, indicating a better ability on their part to describe their beliefs. During the first interviews, these faculty articulated an average of 3 unique beliefs (lowest observation equaled to 1 unique belief, whereas the highest observation equaled to 6) while during the second interview they expressed an average of 10 unique beliefs (lowest observation equaled to 9 unique beliefs, whereas the highest observation equaled to 11). P11 shifted to "instructor-centered beliefs;" P5 and P7 shifted to "student-centered beliefs."

Two faculty showed desirable shifts from the first to second interviews: from "transitional beliefs" to "student-centered" for P4 and from "instructor-centered" to "student-centered" for P6. In the second interview, P4 no longer mentioned beliefs such as "students need broad exposure to a variety of topics" and "students learn by paying attention," whereas P6 did not mention beliefs such as "curriculum is a fixed agenda" and "students learn by listening to the instructor." P4's belief that "students learn from each other" remained constant from the first to second interview, whereas it was first mentioned by P6 in the second interview.

However, a shift from "student-centered" to "teacher-centered" was observed from P12. Going from the first to second interview, this participant no longer mentioned the following beliefs: "students can learn from each other," "students learn with instructor's guidance" when engaged in activities, "too much content is bad for students," and "depth of content coverage promotes conceptual understanding." P12's belief that "different students put in different level of effort" remained constant from the first to second interview. However, the beliefs "students learn by listening to the instructor" and "by paying attention in class" were mentioned by P12 only in the second interview.

Relationship between Changes in Faculty Beliefs and Their Personal and Contextual Factors

Our second research question aimed to explore factors that the TCSR model identifies as potential influencers on beliefs about teaching and learning. We define change in belief group as the shift between clusters of beliefs over time. Four faculty moved towards the "student-centered" cluster from the first to second interview and were denoted as the "Shifted to Student-Centered" group (n = 4). Some faculty remained in the same cluster thus showed no change and were denoted as the "Did Not Change" group (n = 3). Two faculty moved to "instructor-centered" thinking which comprised the "Shifted to Instructor-Centered" group (n = 2).

Participants completed several surveys as part of the workshop evaluation where faculty were originally recruited. These surveys collected information from within the factors in the TCSR Model and were analyzed to potentially explain changes in faculty thinking over time. This analysis focused on survey items determined to fit under the personal and contextual factors as these were inherent to the instructors themselves or their institutional context. The list of survey items corresponding to each factor and how each group of faculty (i.e., those who shifted toward student-centered, those who did not change and those who shifted toward instructor-centered) answered these items is presented in supplemental materials. Below we describe the items that indicated distinct patterns among the three group of faculty (Table 5).

Table 5 - Patterns found within personal and contextual factors in changes of faculty beliefs over time

Factors		**Shifted to Student-Centered (N=4)**	**Did Not Change (N=3)**	**Shifted to Instructor-Centered (n=2)**
Contextual	Broader Cultural Context	Faculty in this group consult JCE papers more often than faculty in the other two groups (3/4 consulted 1-2 times per semester)	Most faculty in these groups consult JCE less frequently than those in the other group (1 and 0 consulted 1-2 times per semester, respectively)	
Contextual	Department Context	In comparison to faculty in the other two groups, most (3/4) were able to consult CER faculty about teaching and did so about 1-2 times/year.	3/5 of faculty in these two groups did not have a CER colleague in their department and, therefore, were unable to ask them for advice on teaching.	
Contextual	Course Context	3/4 did not change course contexts (i.e. same subject and course level)	3/5 had some changes (level and/or subject) in course taught between the first and second interview	
Personal	Nature and extent of instructor's preparation to teach	Faculty in this group had the least exposure to EBIPs as students.	Overall, faculty in this group had moderate experience with EBIPs as students.	Faculty in this group had the most experience with EBIPs as students.
Personal	Nature and extent of instructor's continued learning efforts	Very few faculty in this group attended any professional development prior to the CSC NFW. Faculty's familiarity with EBIPs prior to the CSC NFW hardly overlapped with those they experienced as a student, so it is unclear where or how these faculty learned about the additional EBIPs. However, after attending the CSC NFW, they have the	Very few faculty in this group attended any professional developments prior to the CSC NFW. For most faculty in this group, over half of the EBIPs they were familiar with overlapped with those they experienced as a student, so most of their EBIPs knowledge came from their experience as	All faculty in this group had attended professional development prior to the CSC NFW. The majority of the EBIPs this group was familiar with overlapped with those they experienced as students. Even with attending professional development it seems these faculty did not gain much

		highest percent attendance of other professional developments.	students. But it is unclear where or how these faculty learned about the additional EBIPs.	knowledge/experience of new EPIPs.

In respect to the contextual factors, we found some similarities and a few interesting differences among the three change belief groups (see Table 5 and supplemental materials for more details). At the institutional context level, faculty of all groups were employed at a variety of institution classification types according to Carnegie Classification. In the broader cultural context, when it came to whether faculty sought advice to improve their teaching, those who "Shifted to Student-Centered" consulted papers from the *Journal of Chemical Education* more often than the faculty in the other two groups (data based on the year 3 survey). Additionally, the majority of faculty in the "Shifted to Student-Centered" group were able to consult Chemistry Education Research (CER) faculty within their department about teaching and did so about 1-2 times/year (data based on the year 3 survey). In contrast, most of the faculty in the other two groups did not have a CER colleague in their department and, therefore, were unable to ask CER specialists for advice on teaching. Due to the small sample size we make no claims that this is the reason why the "Shifted to Student-Centered" group displayed the desirable shift to more student-centered thinking. At the same time, it is interesting to note that perhaps the presence of these positions impacted individual faculty or department cultures.

As this was a longitudinal study and faculty may teach a variety of courses over time, we noted that five faculty indicated teaching different courses during the first and second interview. Examining change in beliefs by course context revealed some interesting findings. The majority of faculty in the "Shifted to Student-Centered" group did not change course contexts between the first and second interviews, meaning that these faculty taught the same course discipline and at the same level (graduate or undergraduate). This might explain their shift to more student-centered beliefs, as they had an opportunity to teach the same course several times and likely had more time to reflect on their practices, learn about students' difficulties with content and test strategies to improve their learning. In contrast, less than half of the faculty in the other two groups taught the same course context between the first and second interviews. In fact, faculty in the "Did Not Change" group showed the most variety of change within course context, yet their beliefs remained unchanged, indicating that for these faculty their beliefs were seemingly independent from their course context. Future studies with larger sample size should further explore the extent to which repeated experiences in teaching the same course lead to shifts toward student-centered beliefs.

Across the personal factors investigated from those outlined in the TCSR Model, we saw some similarities between the change belief groups (see Table 5 and supplemental material). Demographic evaluation showed that faculty in each change belief group contained a variety of teaching experience and nearly even sex representation. Most faculty within each group continued professional development between the first and second interviews (between Fall 2016/Spring 2017 and Spring 2019). The "Shifted to Student-Centered" group indicated that they had very little experience with EBIPs when they themselves were students. In addition, very few faculty in the "Shifted to Student-Centered" group attended any professional development prior to the CSC NFW. However, after attending this workshop, they participated in a higher number of other professional development opportunities in comparison to the faculty in the other two groups. These survey results highlight that in comparison to the faculty in the "Did Not Change" and "Shifted to Instructor-Centered" groups, faculty in the "Shifted to Student-Centered" group actively sought professional development. This is one potential reason that explains their shift to more student-centered beliefs over the course of this longitudinal study.

Limitations

While this study shed light on the changes over time in the beliefs about teaching and learning of early career chemistry faculty, the small sample size is its primary limitation. Having examined longitudinal changes in the beliefs of only nine faculty participants, we do not claim generalizability of our findings. The small sample size also does not allow for the use of cluster analysis in a predictive manner. Therefore, we used cluster analysis solely in an exploratory fashion, to allow for a deeper qualitative examination of patterns in the belief systems of the research participants. Although we examined several factors described in the TCSR Model, we could not explore several due to small sample size and did not explore faculty instructional practices. This was also due to the fact that nearly half of our faculty participants taught different courses during the longitudinal data collection.

Conclusions and Implications

This study sought to identify how teaching beliefs of early-career chemistry professors change over time. Overall, the number of beliefs about teaching and learning increased from the first to second interview. This difference is particularly evident for faculty who were initially in the cluster of "limited number of beliefs" and who shifted to other clusters, indicating a better ability on their part to describe not only what they are doing in their classrooms, but also why they are doing it.

Despite the overall increase in the number of the articulated beliefs, the substance and the message of the beliefs remained fairly similar to the beliefs expressed during the first interviews about two and half years ago as suggested by almost identical code books from the first to second interviews. This implies that the sophistication of beliefs did not change as an artifact of additional teaching experience. Both, during the first and second interviews, participants expressed a range of beliefs, some better aligned with the literature on best practices of teaching and learning and some worse; however, most of the articulated beliefs lacked in depth. Additionally, the few new idiosyncratic beliefs that were expressed during the second interviews (e.g., “students like lecturing,” “active learning is not uniformly beneficial for all students,” and “students learn when actively taking notes”) were more instructor-centered in their nature (i.e., beliefs that support the transmission model of learning). This might be attributed to the complexities of the educational process and how numerous constraints and pressures affect instructor’s thinking. This finding is similar to the finding of Fletcher and Luft (2011), who reported that the five prospective secondary science instructors in their study reverted to more traditional beliefs once in the classroom in their first year of teaching. They explained that some beliefs are held very tightly and remain consistent, whereas others can drastically change when exposed to the complexities of classroom teaching.

Although this study explored belief systems of a fairly homogeneous sample of participants, there was a noticeable variation in the sophistication of faculty’s beliefs. These results highlight the need for instructional reform facilitators to recognize the diversity of beliefs present within a somewhat homogeneous group of instructors and differentiate the learning experiences accordingly. Based on the TCSR Model, various factors could be responsible for this variability: contextual factors (e.g., cultural, school, and classroom contexts) as well as personal factors (e.g., previous experiences as students and nature and extent of instructor’s continued learning efforts) (Gess-Newsome et al., 2003). We found one aspect within the personal factors explored in this study that may have led faculty to change their thinking over time: more faculty who shifted toward student-centered beliefs had participated in professional development experiences after the CSC NFW. Additionally, we found a few notable differences within the contextual factor between change belief groups that may relate to change seen in faculty beliefs over time. In particular, the presence of a CER colleague in the department and faculty consultation of papers published in the *Journal of Chemical Education* were associated with faculty who shifted toward student-centered beliefs. Andrews and colleagues' (2016) study found discipline-based education researchers (DBERs) to be agents of change in their departments. This may explain in part the change seen for those faculty who "Shifted to Student-Centered" as the majority had access to and reached out to CER faculty in their department to seek advice on their teaching.

A third of the sample in our study held on to their instructor-centered beliefs throughout the study, which also highlights the need for a continuous professional development that will challenge and cultivate beliefs that are better aligned with reform-based instructional practices. One participant held instructor-centered beliefs over the entire course of this study. As suggested by Pajares (1992), one key characteristic of beliefs is that the older beliefs are held more strongly and are resistant to change. This might suggest that without any professional development opportunities that challenge their thinking, beliefs of this instructor might remain instructor-centered over the course of their entire career. This is particularly concerning in the light of the results from a recent nationwide scale study that identified that chemistry instructors who held instructor-centered beliefs employed lecture-based teaching styles, whereas instructors whose classrooms reflected a reformed environment held student-centered beliefs (Gibbons et al., 2018).

To gain deeper, more generalizable insights, future research should aim to reproduce this study with a larger sample of faculty and monitor their beliefs over a longer period of time. It is also critical to identify how the changes over time in the beliefs of chemistry faculty are aligned with changes in their instructional practices, as well as the impact of these beliefs and practices on student learning outcomes. Finally, as Fang noted (1996, p. 59), the community needs to engage with the practically more important concern of understanding "how instructors apply their theoretical beliefs within the constraints imposed by the complexities of the classroom life."

Conflicts of Interest

There are no conflicts of interest to declare.

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Appendix

Table S1. 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 the main strengths you have as a teacher?
8. What are some areas of your teaching that you would like to improve on?
9. Which scenario is worse; getting through the all of topics while only a minority of students understand them or getting through only some of the topics while a majority of students understand them?

Figure S1. Dendrogram illustrating the results of the agglomerative hierarchical cluster analysis for the post-interview data

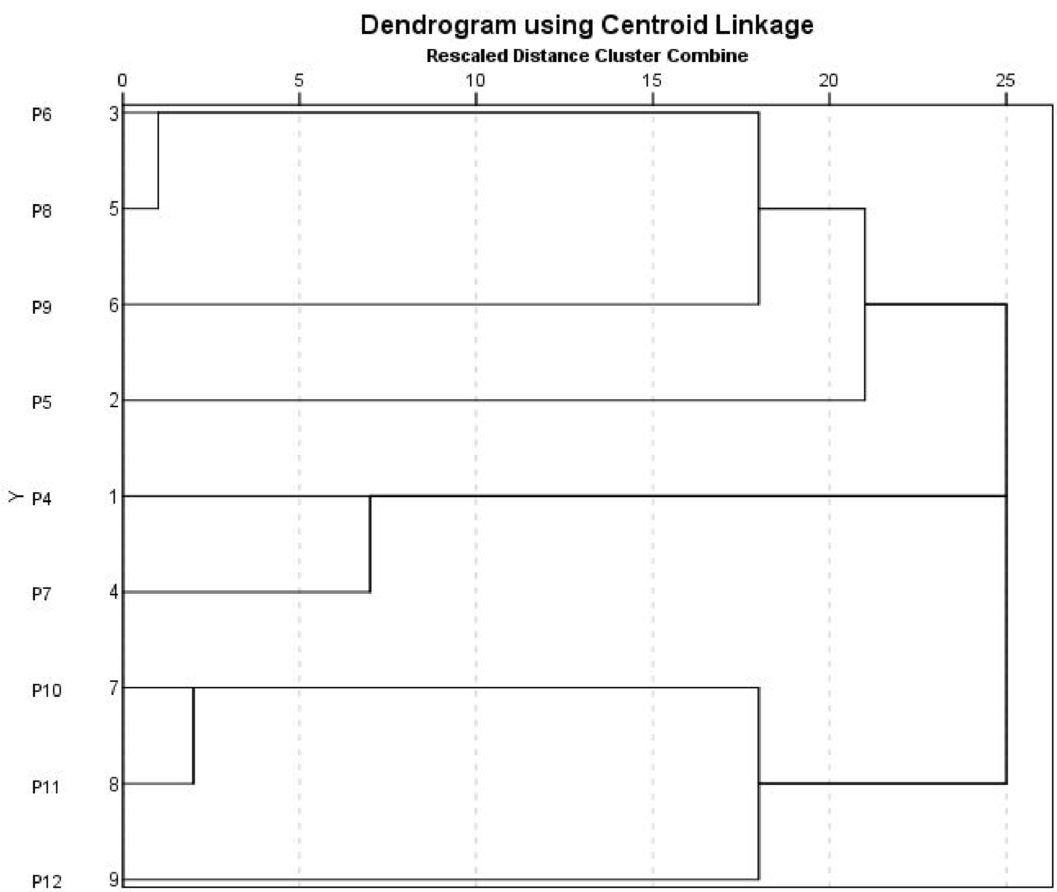

Table S2. Survey items used in this study. We indicate in parenthesis on which survey(s) the items was asked. Items marked with * were not included in the analysis since less than 50% of the faculty in at least one of the clusters provided answers for these items.

Personal Factor Items

1. What type of institution did you attend as an undergraduate student? (Pre)

2. How long have you been in your current position? (Pre)

3. Have you previously participated in program(s), workshop(s) and/or course(s) on teaching? (Pre)

4. Since the workshop, have you participated in program(s), workshop(s) and/or courses on teaching? (1, 3 YR)

5. How many webinars provided by the CSC NFW organizers have participated in since the workshop? (3 YR)

6. Please indicate your level of familiarity with each of the following instructional strategies and methods: (Pre)
    a. Think-Pair-Share: Posing a problem or question, having students work on it individually for a short time and then forming pairs and reconciling their solutions. Followed by a whole classroom discussion of students' responses.
    b. Just-in-time Teaching: Asking students to individually complete homework assignments a few hours before class, reading through their answers before class and adjusting the lessons accordingly.
    c. Peer Instruction: A specific way of using concept tests in which the instructor poses the conceptual question in class and then shares the distribution of responses with the class. Students form pairs, discuss their answers, and then vote again.
    d. Teaching with Case Studies: Asking students to analyze case studies of historical or hypothetical situations that involve solving problems and/or making decisions.
    e. Process Oriented Guided Inquiry (POGIL): In groups, students complete a worksheet designed around the learning cycle.
    f. Problem-Based Learning (PBL): Acting primarily as a facilitator and placing students in self-directed teams to solve open-ended problems that require significant learning of new course material.
    g. SCALE-UP Classroom: Students work in small groups on hands-on activities, simulations, interesting questions or problems for the majority of the class.
    h. Interactive Lecture Demonstration: Three-step process where students predict, experience and reflect on a demonstration experience.
    i. Collaborative Learning: Asking students to work together in small groups toward a common goal.

j. Cooperative Learning: A structured form of group work where students pursue common goals while being assessed individually.
k. Teaching with Computer Simulations (Interactive Animations): Interactive computer animations, in which variables of the system or other aspects can be manipulated, are used to supplement classroom instruction.
l. Teaching with Molecular Animations: Computer animations, in which chemical phenomena are represented at the particulate level, are used to supplement classroom instruction.
m. Clickers: Using a classroom response system to collect data from students.
n. Concept Maps: Students diagram the relationships that exist between concepts.
o. Formative Assessment: Formal or informal assessments designed to gain timely feedback on students understanding of material and provide opportunity for instructor to modify instruction accordingly.
p. Concept Tests/Inventories: Assessment instruments designed to identify misconceptions.

1 I have never heard of it
2 I have heard the name but don't know much else
3 I am familiar but have not used it
4 I am familiar and plan to implement it
5 in the past I have used all or part of it but am no longer using it
6 I currently use all or part of it

7. Please indicate the instructional and assessment strategies/methods that you have experienced as a student: (check all that apply) (Pre)
   a. Think-pair-share
   b. Just-in-Time Teaching
   c. Peer Instruction
   d. Teaching with case studies
   e. Process Oriented Guided Inquiry Learning (POGIL)
   f. Problem-Based Learning (PBL)
   g. SCALE-UP classroom
   h. Interactive lecture demonstration
   i. Collaborative Learning
   j. Cooperative Learning
   k. Teaching with computer simulations (interactive demonstrations)
   l. Teaching with molecular animations
   m. Clickers
   n. Concept Maps
   o. Formative Assessment
   p. Concept Tests/Inventories
   q. None of these

8. Did you attend the following conferences within the last year? (*1 YR and 3 YR)

a. Biennial Conference in Chemical Education
b. Gordon Research conference: Chemistry Education Research and Practice
c. Educational talks at national scientific meetings
d. National and/or regional meeting of the National Science Teachers Association
e. Other education-oriented conferences; please specify

Contextual Factor Items

1. Suppose you wanted to get advice about issues concerning teaching. Which source would you turn to for assistance or advice? Check one response for each suggested source of assistance. If you do not have access to the source, choose Not Applicable (3 YR)
    a. Department Chair
    b. Faculty within your department conducting bench chemistry
    c. Faculty within your department conducting research in chemical education
    d. Lecturer/professor of practice in your department
    e. Science colleague outside your department but at your institution
    f. A colleague in the College of Education (or equivalent) at your institution
    g. Faculty outside your institution conducting bench chemistry
    h. Faculty outside your institution conducting research in chemical education
    i. Your Ph.D. and/or postdoc advisor
    j. Students in your courses or in your research group
    k. Teaching and learning center
    l. Professional association
    m. Education texts or education-oriented websites; please specify
    n. The Journal of Chemical Education
    o. The Journal of College Science Teaching
    p. The Chemistry Education Research and Practice journal
    q. The education section in Science
    r. Other pedagogical journals
    s. Other sources; please specify

    1 not applicable
    2 never or very rarely
    3 1-2 times per year
    4 1-2 times per semester
    5 1-2 times per month
    6 at least once a week

2. Within this past year, how many courses did you teach per semester on average? (1, 3 YR)

3. Approximately what is the distribution of your appointment? (Total should add to 100%) If a field is Not Applicable, please enter 0. (Pre)
    a. Teaching
    b. Research

c. Service
d. Administration

*4. How much do your departmental colleagues have expectations for your teaching methods? (1 YR and 3 YR)
a. Expectation to use techniques other than lecturing
b. Expectation to have students be actively involved in class
c. Expectation to use a variety of teaching methods

not at all
very little
some
quite a bit
a great deal

*5. To what extent has your department been engaged in improving teaching practices of faculty within this past year? (1 YR and 3 YR)

not at all
a little
somewhat
very
extensively

Table S3 – Contextual factors investigated to examine change in beliefs over time. Only items that had a response rate of 50% or higher within each cluster are included.

TCSR Factor	Item	Change in Belief Clusters Over Time																	
		Shifted to Student-Centered (N=4)						Did Not Change (N=3)						Shifted to Instructor-Centered (n=2)					
	Broader Cultural Context																		
	Suppose you wanted to get advice about issues concerning teaching. Which source would you turn to for assistance or advice? **Resource:**	**1/4 No response**																	
	Education literature:	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
	Journal of Chemical Education	0	0	0	3	0	0	0	1	1	1	0	0	0	1	0	1	0	0
	The Journal of College Science Teaching	0	3	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0
	Chemistry Education Research and Practice	0	2	0	1	0	0	0	3	0	0	0	0	0	2	0	0	0	0
	The education section in Science	0	3	0	0	0	0	0	3	0	0	0	0	0	1	2	0	0	0
	Other pedagogical journals	2	1	0	0	0	0	1	2	0	0	0	0	0	2	0	0	0	0
	Education texts or education-oriented websites	0	2	0	0	1	0	1	0	0	2	0	0	0	2	0	0	0	0
	Human resources:																		
	Faculty outside your institution conducting bench chemistry	0	1	2	0	0	0	0	1	2	0	0	0	0	0	1	1	0	0
	Faculty outside your institution conducting research in chemical education	0	3	0	0	0	0	0	2	1	0	0	0	0	2	0	0	0	0
	Your Ph.D. and/or postdoc advisor	0	3	0	0	0	0	0	1	2	0	0	0	0	1	1	0	0	0
	Professional association	0	2	1	0	0	0	0	3	0	0	0	0	0	2	0	0	0	0
	School Context																		
	Suppose you wanted to get advice about issues concerning teaching. Which source would you turn to for assistance or advice? **Resource:**	**1/4 No response**																	
		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
	Teaching and learning center	0	1	2	0	0	0	0	2	0	1	0	0	0	1	1	0	0	0
	Science colleague outside your department but at your institution	0	0	2	1	0	0	0	1	2	0	0	0	1	0	0	1	0	0
	A colleague in the College of Education (or equivalent) at your institution	0	2	1	0	0	0	0	3	0	0	0	0	0	1	1	0	0	0

Carnegie Classification	2/4 Very High Research Activity 1/4 Doctoral /Professional 1/4 Master's: larger programs	1/3 Very High Research Activity 2/3 high research activity	1/2 Very High Research Activity 1/2 Master's: larger programs
Department Context			
Suppose you wanted to get advice about issues concerning teaching. Which source would you turn to for assistance or advice? **Resource:**	**1/4 No response** 1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6
Department Chair	0 1 1 0 1 0	0 2 0 1 0 0	0 0 2 0 0 0
Faculty within your department conducting bench chemistry	0 0 1 0 2 0	0 1 1 0 1 0	0 0 0 0 2 0
Faculty within your department conducting research in chemical education	0 0 3 0 0 0	2 0 0 1 0 0	1 0 1 0 0 0
Lecturer/professor of practice in your department	0 1 1 0 1 0	0 0 2 1 0 0	0 0 1 0 1 0
Students in your courses or in your research group	0 0 0 3 0 0	0 0 2 1 0 0	0 0 0 2 0 0
Average Appointment % Teaching	36 ± 6.4 %	31.7 ± 5.8 %	30 ± 28.3%
Research	44.8 ± 7.5 %	51.7 ± 11.5 %	65 ± 28.3%
Service	16.8 ± 10.4 %	13.3 ± 5.8 %	5 ± 0%
Administration	2.5 ± 5.0 %	3.3 ± 5.8 %	0 ± 0%
# courses taught on average per semester In 1 YR survey	3/4 One course **1/4 No response**	2/3 One course 1/3 Two courses	2/2 One course
In 3 YR Survey	2/4 One course 2/4 Two courses	3/3 One course	1/2 One course 1/2 Two courses
Classroom Context			
Course Context change from Post to 3 YR	3/4 same course & level 1/4 same course, change level	1/3 same course & level 1/3 same course, change level 1/3 change course, same level	1/2 same course & level 1/2 same course, change level

Table S4. Personal factors investigated to examine change in beliefs over time. Only items that had a response rate of 50% or higher within each cluster are included.

TCSR Factor	Item	Change in Belief Clusters Over Time		
		Shifted to Student-Centered (N=4)	**Did Not Change (N=3)**	**Shifted to Instructor-Centered (n=2)**
Personal	**Demographic Profile**			
	Sex	2/4female 2/4 male	2/3 female 1/3 male	2/2 female
	Types and Years of Teaching Experience			
	Year of teaching experience as faculty	1/4 third year 2/4 fourth year 1/4 fifth year	1/3 third year 1/3 fourth year 1/3 fifth year	1/2 third year 1/2 fourth year
	Nature and extent of teachers’ preparation to teach			
	Type of institution attended as an undergraduate student	3/4 Research university or institution with Masters and/or Ph.D. as the highest degree in chemistry offered 1/4 4-year university or college with BS, BA, or Masters as the highest degree in chemistry offered	2/3 Research university or institution with Masters and/or Ph.D. as the highest degree in chemistry offered 1/3 4-year university or college with BS, BA, or Masters as the highest degree in chemistry offered	1/2 Research university or institution with Masters and/or Ph.D. as the highest degree in chemistry offered 1/2 4-year university or college with BS, BA, or Masters as the highest degree in chemistry offered
	Average % of EBIPs experienced as a student (of 16 listed)	2.8 ± 2.1 (17 ± 13%)	4.0 ± 1.7 (25 ± 11%)	8 ± 1.4 (50 ± 9%)
	Overlap between experienced as a student and familiarity	24 ± 20%	55 ±14%	73 ± 21%
	Nature and extent of teachers' continued learning efforts			
	Professional Development attended Prior to NFW	1/4 Yes 3/4 No	1/3 Yes 2/3 No	2/2 Yes
	Additional Professional Development in **past 2 years**	3/4 Yes 1/4 No	2/3 Yes 1/3 No	1/2 Yes 1/2 No

	Average # of webinars participated (provided by CSC NFW organizers)	5.5 ± 1.3	5.0 ± 1.0	5.0 ± 1.4
	Conferences attended in past year:	**1/4 No response**		
	Biennial Conference in Chemical Education	3/3 No	3/3 No	2/2 No
	Gordon Research conference: Chemistry Education Research and Practice	3/3 No	3/3 No	2/2 No
	Educational talks at national scientific meetings	3/3 No	2/3 No	2/2 Yes
	National and/or regional meeting of the National Science Teachers Association	2/3 No	3/3 No	2/2 No
	Other education-oriented conferences; please specify	3/3 No	3/3 No	1/2 Yes