Exploring Relationships that College Instructors Seek to Build with Intention in Chemistry Classrooms

Journal:	*Chemistry Education Research and Practice*
Manuscript ID	RP-ART-07-2023-000198.R2
Article Type:	Paper
Date Submitted by the Author:	11-Oct-2023

Complete List of Authors:	Moreira, Patricia; The University of Arizona, Chemistry and Biochemistry Talanquer, Vicente; University of Arizona, Chemistry and Biochemistry

ARTICLE

Exploring Relationships that College Instructors Seek to Build with Intention in Chemistry Classrooms

Patricia Moreira*[a] and Vicente Talanquer [a]

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

DOI: 10.1039/x0xx00000x

Teaching is a complex activity that demands paying attention to diverse components and relationships that affect the learning process, and acting with intentionality to build and nurture those connections. In this qualitative research study, we proposed and used an intentional-relational framework to explore differences in the relationships that four general chemistry instructors sought and acted to build with intention in their classes. Our goal was not to evaluate the quality of instruction but rather to characterize instructors' practices to gain insight into educational relationships that may affect student performance. All instructors in our sample manifested a strong interest in helping students succeed in their studies and relied on a variety of resources designed and integrated into their courses to support student learning. They mostly differed in the extent to which they attended and responded to contextual issues, intentionally seeking to make content relevant to students, helping them build connections between their interests and the discipline, and adapting resources to create more inclusive learning environments. These differences seem to affect student performance in common exams. Our study highlights the importance of analyzing the relationships that instructors build with intention to support professional development and teacher reflection, and better understand the impact of instructors' decisions on student performance.

Introduction

Results from research in discipline-based education at the college level in the past twenty years indicate that pedagogical models and instructional strategies that actively and interactively engage students in co-constructing meanings are more likely to result in meaningful learning and successful performance than traditional methods of teaching (National Research Council, 2012; 2015; Lombardi, *et al.*, 2021). These studies also show that structured active engagement with central ideas and disciplinary practices through well-designed tasks in collaborative learning environments benefits all students, particularly those from minoritized groups (Freeman, *et al.*, 2014; Theobald, *et al.*, 2020).

The significant benefits of active versus passive approaches to college STEM teaching have been made explicit through ambitious meta-analyses that aggregate data from multiple institutions and classrooms (Freeman, *et al.*, 2014; Harris, *et al.*, 2020; Theobald, *et al.*, 2020). Results from these types of analyses should be interpreted cautiously as learning environments grouped within the "active learning" category may have had different characteristics in terms of the curricula used in the compared courses, the specific teaching strategies that were applied and the fidelity of their implementation (Stains and Vickrey, 2017), and the assessment tools employed to evaluate student performance.

[a] *Department of Chemistry and Biochemistry, University of Arizona, Tucson, AZ 85721, USA. Email: pmoreira@arizona.edu.*

At our institution, for the past ten years all sections of the introductory general chemistry course for STEM majors have been taught by a set of instructors using a common reformed curriculum and active learning strategies (Talanquer and Pollard, 2010; 2017). All these instructors teach large-enrollment classes (>200 students) using common exams to evaluate student performance throughout the semester. This setup creates a unique opportunity to explore the differential effects of course implementation on student achievement controlling for many relevant variables. Analysis of student performance in common exams across several semesters for the four main instructors teaching the first and second semesters of the general chemistry course at our institution revealed significant differences for students with similar prior academic preparation. Thus, we were interested in characterizing differences in these instructors' approaches to teaching that could relate to the observed differences in exam performance. Teaching is a complex activity taking place in complex environments, particularly when working with more than two hundred diverse students in a classroom (Biggs, 1993). Many factors can be expected to affect student outcomes. Consequently, rather than looking for specific teacher decisions and actions potentially responsible for differential student performance, we sought to build a more holistic characterization of each instructor's approach to teaching by analyzing the relationships they seek to build with intention in their classrooms. This analysis exposes the complex relations between instructors' intentions and actions and student performance.

Effective college teaching

There is now a vast research literature that presents evidence of the educational benefits of pedagogies and instructional models that focus learning on a core set of integrated disciplinary ideas and practices, set high expectations for learning, make learning goals explicit and relevant to students, clarify to students how instructional activities relate to course goals, include structures that scaffold and foster student learning, and provide prompt and specific formative feedback (Freeman*, et al.*, 2011; Eddy and Hogan, 2014; Schneider and Preckel, 2017; Artze-Vega*, et al.*, 2023). Effective course structures provide direct and compelling guidance to students on how to prepare for learning, engage in collaborative activity to co-construct meanings, study course material using elaboration strategies, and activate metacognitive monitoring and control.

Teaching approaches at the college level that incorporate the practices described above are often grouped under the umbrellas of "active learning" (Lombardi*, et al.*, 2021), "evidence-based teaching" (National Research Council, 2015; Mintzes and Walter, 2021), and "pedagogies of engagement" (Smith*, et al.*, 2005). Successful instructional models in chemistry, such as Process-Oriented Guided Inquiry Learning (POGIL), Peer-Led Team Learning (PLTL), and Problem-Based Learning (PBL) (Eberlein*, et al.*, 2008; Hodges, 2018), as well as approaches categorized as "flipped learning" (Seery, 2015; DeLozier and Rhodes, 2017), purposefully integrate several of those practices to guide student learning inside and outside the classroom.

In interactive learning environments, student learning is affected by the nature of the instructional tasks and educational resources that guide and support the exploration and construction of central ideas while engaging in authentic disciplinary practices (Roberson and Franchini, 2014). Well-designed activities and resources offer students rich opportunities to develop meaningful understandings by applying the type of thinking that is characteristic of the discipline in the analysis of problems of individual, societal, or vocational relevance (Stuckey*, et al.*, 2013). From this perspective, meaningful learning takes place when students conscientiously and agentively integrate core disciplinary knowledge with prior knowledge (Ausubel, 2000) by leveraging their personal experiences and cultural and social capitals in the construction of understandings that are relevant to them and the communities in which they live (Moll*, et al.*, 1992). Effective instructional tasks engage students in constructive and interactive activities that lead to the creation of shared meanings (Chi and Wylie, 2014). These types of activities often involve students in analyzing data to infer patterns, applying or constructing models to make sense of data, drawing conclusions and building arguments to support them, and generating explanations of issues of interest (Lombardi*, et al.*, 2021).

Learning is enhanced when the construction of meanings involves productive interactions between students and between students and instructors. These interactions are fostered through collaborative activity in which students share information and insights, engage in co-constructive conversations in which knowledge is elaborated, and receive prompt, specific, and contextualized feedback that promotes reflection and advances student thinking toward the learning goals (Gillies, 2016; Hodges, 2018). Through these interactions, students adopt the language, practices, and norms of the discipline as they learn to participate in shared endeavors (Van den Bossche*, et al.*, 2011; Becker*, et al.*, 2013; Moon*, et al.*, 2017). Nevertheless, these processes are influenced by students' prior knowledge and experiences, how they frame in-class tasks and collaborative activity, the feedback they receive, and how their performance is evaluated (Scherr and Hammer, 2009). It is thus critical to develop classroom cultures in which sensemaking and relevant problem-solving are valued, proper resources, structures, and guidance are provided, and intellectual activity is contextualized in meaningful ways for all students (Fitzgerald and Palincsar, 2019).

Learning environments should also be designed to create a classroom climate in which all students feel welcome, respected, and valued (Dewsbury and Brame, 2019; Wilson-Kennedy*, et al.*, 2020). Inclusive, equitable, and culturally responsive pedagogies rely on instructional strategies that promote personal agency in the learning process, positively affect students' self-perception (self-concept, self-efficacy, science identity), create a sense of belonging, and foster metacognition through dialogue, modeling of strategies, and critical reflection (Artze-Vega*, et al.*, 2023).

Intentional-relational framework

The analysis of the research literature on college STEM teaching suggests that effective practice demands that instructors take explicit intentional actions to build strong and meaningful relationships between central educational actors and components (Lombardi*, et al.*, 2021; Paguyo*, et al.*, 2022). An emphasis on building relationships between core elements in education has been at the center of the Continental European educational tradition in which teaching is conceived in terms of a "Didaktik triangle" which interconnects the content to be learned (Ct), the student (S), and the teacher (T) (Fig. 1) (Hopmann, 2007; Hudson, 2007). In this tradition, teaching and learning are seen as complex relational activities taking place within the triangle but it is common to approach their analysis in terms of pairs of relationships: Teacher-student (pedagogical), student-content (learning), and teacher-content (didaktikal) as conceptualized in the "didaktik" tradition in Continental Europe (Hopmann, 2007).

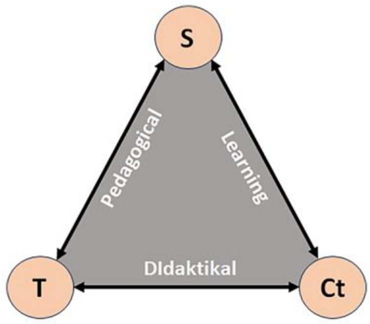


Fig. 1 The didaktik triangle model for teaching and learning highlighting main relationship pairs (pedagogical, didaktikal, learning) between students (S), teacher (T), and content (Ct).

There are, however, other important elements and relationships not represented in the didaktik triangle in Fig. 1 that affect teaching and learning in diverse settings. For example, researchers in mathematics (Rezat and Sträßer, 2012) and digital learning (Tall, 1986; Anderson, 2004) have highlighted the central role that artifacts of different types play in mediating the interactions between student, teacher, and content. These artifacts include physical (e.g., textbooks, computers, videos) and non-physical (e.g., visual representations) tools that structure and support the learning process. From an activity theory perspective (Engeström, 1987), artifacts are instruments that mediate students' learning activity but their use is orchestrated by the teacher. To capture these additional relationships the didaktik triangle has been transformed into the didaktik tetrahedron represented in Figure 2 (Rezat and Sträßer, 2012). Each of the lateral faces in the tetrahedron encapsulates a different perspective on the role of artifacts in teaching and learning (e.g., the triangle student-artifact-content depicts the instrument-mediated activity of learning).

From a sociocultural perspective, the teacher's and students' actions are mediated by cultural tools that organize and amplify teaching/learning processes through their integration into practice (King, 2012; Geiger, 2014). In this activity system, a variety of contextual factors also influence the interactions between students, teacher, content, and artifacts. Participants' prior knowledge, experiences, goals, and expectations will affect the social and knowledge dynamics at the class and individual group levels (Reid*, et al.*, 2022; Nennig*, et al.*, 2023). The placement of the course within a curricular sequence, the academic culture, and the institutional setting will influence the teacher's and students' goals and decisions. Thus, "context" should also be considered as a major pillar anchoring critical relationships in classrooms.

Based on these ideas, the didaktik tetrahedron can be expanded into the didaktik pyramid depicted in Fig.3 shaped by five central central elements in teaching and learning: Students (S), Teacher (T), Content (Ct), Context (Cx), and Resources (R). We choose the term "resources" rather than "artifacts" in this representation to make explicit the role of these tools in the learning process and expand the definition to include not only physical but also human resources that may be present in college classrooms (e.g., learning assistants). In this study, we use this expanded representation to propose an

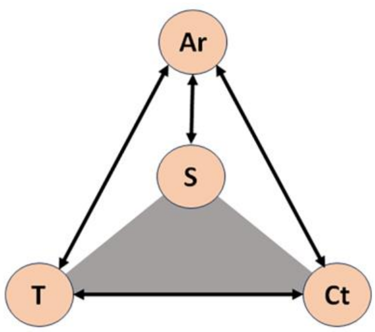


Fig. 2 Didaktik tetrahedron representing interactions between students (S), teacher (T), content (Ct), and artifacts (Ar).

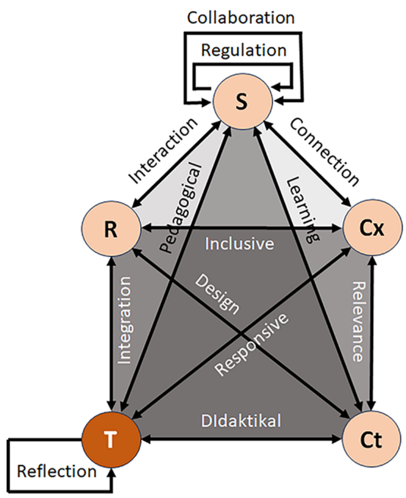


Fig. 3 Didaktik pyramid for teaching and learning representing main relationships between students (S), teacher (T), content (Ct), context (Cx), and resources (R). The teacher corner is highlighted to emphasize that in our intentional-relational model we focus on teachers' role in building the different relations between major components.

intentional-relational model that makes explicit the relationships that effective instructors should intentionally build in college classrooms. The model seeks to highlight that rigorous, inclusive, equitable, and culturally responsive teaching in interactive environments requires building strong relationships between students and the subject matter, between students and their peers, between students and the physical and human resources available to support their learning, and between students, teachers, and contextual issues of relevance to the learners, their communities, and their future professions (Paguyo*, et al.*, 2022; Artze-Vega*, et al.*, 2023). Quality teaching also demands helping students engage in self-regulation and building relations with their current and future selves, and for teachers to connect with themselves as they critically reflect on their practice.

Our intentional-relational model assumes that the different relationships represented in Fig.3 cannot be expected to emerge on their own but rather should be built with intentionality. Intentional teaching requires teachers to be deliberate, thoughtful, and purposeful in making decisions and taking actions to achieve their learning objectives and effectively meet the learning needs of all students (Kilderry, 2015). In our model, this demands purposeful planning and intervention from the teacher to create and foster the following relationships:

- *Teacher-Student (Pedagogical):* Through direct and indirect interactions, teachers build caring connections with their students to help them progress toward the learning objectives, enrich their educational experience, and achieve their professional goals (Friesen, 2017).
- *Teacher-Content (Didaktikal):* Teachers build and use pedagogical content knowledge (Loewenberg Ball*, et al.*, 2008) to design and orchestrate instruction in ways that facilitate students'

construction of meaningful understandings in the discipline and the development of authentic practices in the field.

- *Student-Content (Learning):* Teachers foster student learning by establishing structures and processes that create multiple and diverse opportunities for learners to actively engage with course content and to receive prompt and specific formative feedback (Lombardi*, et al.*, 2021).
- *Content-Resources (Design):* Teachers purposefully design a variety of educational resources, both physical resources (PR) and human resources (HR), that structure and scaffold student learning of core ideas, practices, and ways of thinking in the discipline.
- *Teacher-Resources (Integration):* Teachers meaningfully build, gather and integrate physical and human resources into their teaching that support student learning.
- *Student-Resources (Interaction):* Teachers organize instruction to foster frequent and productive interactions between students and available physical and human resources inside and outside the classroom.
- *Teacher-Context (Responsive):* Teachers select and organize content, implement instruction, and use assessments in manners that are responsive to their students' ideas, ways of thinking, and learning challenges (Gouvea and Appleby, 2022), and to their social and cultural capitals (Gay, 2002).
- *Content-Context (Relevance):* Teachers select content that is individually, socially, and vocationally relevant to students and promotes learners' intellectual development, socio-scientific literacy, and professional competency (Stuckey*, et al.*, 2013).
- *Student-Context (Connection):* Teachers design and implement instruction that helps students build connections between the subject matter and issues of interest and relevance to them.
- *Resources-Context (Inclusive):* Teachers intentionally create structures and provide resources that facilitate equitable access to meaningful and relevant learning opportunities by all students and make them feel valued and supported in their learning (Lawrie*, et al.*, 2017).
- *Student-Student (Regulation):* Teachers create opportunities for students to develop and apply self-regulation strategies (cognitive, metacognitive, affective, behavioral) to control and monitor their learning (Zimmerman, 2008; Hartman*, et al.*, 2022).
- *Students-Students (Collaboration):* Teachers design and implement structures and processes that foster productive collaboration of students inside and outside the classroom (Hodges, 2018).
- *Teacher-Teacher (Reflection):* Teachers intentionally gather information about student learning and interpret it, engaging in reflection-in-action and reflection-on-action (Schon, 1983).

One should expect all these different relationships to be interconnected and interdependent as teaching and learning take place within the didaktik pyramid in Fig. 3. However, their separation facilitates their identification and analysis when characterizing teachers' intentions, decisions, and actions as we did in this study.

Methods

Context and participants

This investigation was carried out at the University of Arizona (UA), a public research-intensive university in the southwest of the USA. Since the second semester (called "fall semester" in the US, versus the first semester of the calendar year called "spring semester") of 2014, the Department of Chemistry and Biochemistry at this institution has offered its two-semester general chemistry course for STEM majors using a reformed curriculum called "Chemical Thinking" (Talanquer and Pollard, 2010; 2017). This curriculum introduces students to chemistry as a way of thinking using essential questions (e.g., How do we distinguish substances? How do we control chemical reactions?) to guide the presentation and discussion of central chemical ideas and student engagement with disciplinary practices. The curriculum also contextualizes learning on the analysis of issues of relevance in the modern world.

For the past seven years, four full-time teaching faculty have been responsible for teaching most of the sections offered for both General Chemistry I (GC-I) and General Chemistry II (GC-II) (with more than 200 students on average per section). Each of these courses is four academic credits/units with a lecture component (150 min/week) taught by an instructor and a lab component (170 min/week) taught by several teaching assistants. The four main general chemistry instructors follow the same curriculum and course outline and collectively build and apply five common exams during a semester (four midterm exams and one final exam). Their instructional practices also include some shared components. All of them engage students in short collaborative activities during a class, interspersed with periods of lecturing and whole-class discussions. Some of the collaborative activities used by different instructors are similar as they were originally created by the curriculum developers, but over time instructors have also developed their own in-class tasks. Additionally, all instructors assign the same weekly homework and apply the same grading system in calculating final grades. Most general chemistry classes are taught in classrooms designed to facilitate collaborative work, but an instructor may be assigned to a traditional lecture hall from time to time. In the fall of 2020, all class sections were offered online due to the COVID-19 pandemic.

The four main general chemistry instructors get different teaching assignments every semester, so they do not always teach the same course. Since the fall of 2014, they have taught GC I four times (fall 2017, fall 2020, fall 2021, fall 2022) and GC II three times (spring 2021, spring 2022, spring 2023) in the same semester. We collected and analyzed students' average performance on all common exams during those semesters as part of this investigation. Additionally, we collected demographic and prior performance data for all students enrolled in the targeted courses and semesters. These data included:

- *Sex:* The UA only reports data for two categories in this area, female (F) and male (M).
- *Race/Ethnicity:* The UA reports only data in which students are designated as one of the listed races/ethnicities. In our analysis, we grouped students into two categories in this area:

Table 1. Demographic information for students enrolled in targeted semesters of General Chemistry I, GC-I (fall 2017, fall 2020, fall 2021, fall 2022), and General Chemistry II, GC-II (spring 2021, spring 2022, spring 2023), for four instructors labelled Inst-R, Inst-Y, Inst-G, and Inst-B. Average Academic Index <AI> and average final grade in GC-I <GC-I> are used as measures of incoming academic preparation in GC-I and GC-II, respectively.

	GC-I							GC-II					
Instructors	# Students	Sex (%)		Race/Ethnicity (%)		<AI>		# Students	Sex (%)		Race/Ethnicity (%)		<GC-I>
		F	M	NALA	WA				F	M	NALA	WA	
Inst-R	1297	58.8	41.2	38.2	61.8	229.7		1465	70.4	29.6	37.0	63.0	3.08
Inst-Y	1073	56.3	43.7	34.6	65.4	236.8		729	68.7	31.3	38.1	61.9	3.08
Inst-G	1121	54.6	45.4	34.4	65.6	238.5		528	67.4	32.6	32.6	67.4	2.95
Inst-B	635	57.6	42.4	35.6	64.4	235.0		527	56.9	43.1	36.4	63.6	2.72
Overall	**4126**	**56.8**	**43.2**	**35.8**	**64.2**	**234.8**		**3249**	**67.3**	**32.7**	**36.4**	**63.6**	**3.00**

1) Students reported as White or Asian (WA) typically represented in STEM fields, and 2) students reported as Native Hawaiian or Pacific Islander, American Indian or Alaska Native, Latinx or Hispanic, and African American or Black (NALA), typically underrepresented in STEM careers.

- *Academic Preparation:* The UA reports students' academic index (AI) as a proxy for incoming academic preparation. This index is calculated using high school GPA or class rank, and SAT or ACT scores (both math and reading/writing) and reported as a categorical range (e.g., 200−224). We used AI as a measure of academic preparation for students enrolled in GC-I. For students in GC-II, we used their grades in GC-I (reported in a categorical range from D (1) to A (4)) rather than their AI as a measure of incoming academic preparation; GC-I grades are more strongly correlated with second-semester course performance than AI. Given that AI ranges and GC-I grades were not reported for some students, our analysis only included students for whom all information was available.

All student data were collected with the approval of the Department of Chemistry and Biochemistry, the Registrar's Office, and the Institutional Review Board (IRB 2101358224) at the UA. A summary of demographic data for students included in the analyzed sample for each of the four instructors (labeled Inst-R, Inst-Y, Inst-G, and Inst-B) in the targeted semesters is presented in Table 1. Note that the percentage of males decreases considerably between the first and second semester. This is mostly due to degree requirements as many engineering students, who are predominantly male, are only required to take the first course in the general chemistry sequence.

Given that our main interest in this section is to present trends in performance in common exams of students enrolled in course sections taught by different instructors, we depict in Figs. 4a and 5a linear regression estimates for average exam grades (average over the five common exams in a semester) as a function of incoming academic preparation in GC-I and GC-II, respectively. Average exam grades for GC-I students were grouped into five groups corresponding to the following AI ranges: E (0-174), D (175-199), C (200-224), B (225-249), A (>250), while grades for GC-II students were grouped based on letter grade in GC-I spanning from D to A (students with a failing grade in GC-I cannot enroll in GC-II). Linear regression analyses indicated that the average grade differences between students in the top and bottom performing sections in both courses were statistically significant ($p < 0.001$), with an average grade difference of 3.9% (0.65 SE) for exams in GC-I and 3.3% (0.67 SE) for exams in GC-II. Notice that, in general, grade differences between course sections become more pronounced for students with lower incoming academic preparation.

We also analyzed the difference in average exam grades between groups of students based on sex and race/ethnicity. The corresponding results are shown in Figs. 4b and 4c for GC-I and in Figs. 5b and 5c for GC-II students. In these figures, the Grade Difference based on sex was calculated by subtracting the estimated exam grades for females from the estimated exam grades for males with equivalent incoming academic preparation, while the Grade Difference based on race/ethnicity was calculated by subtracting the estimated exam grades for NALA students from the estimated exam grades for WA students with equivalent incoming preparation. Thus, positive values for these differences indicate a higher grade for males and WA students in each course section. This means, for example, that exam grades in GC-I (Fig. 4b) for male students in the "D" range of incoming preparation were on average 6.0 points higher than those of females in the same range in all course sections, while average exam grades for WA students in the "D" range were 6.5 higher than those of NALA students in Inst-Y's sections and 3.8 points higher in Inst-R's sections. Similarly to what was reported in a prior study (Tashiro and Talanquer, 2021), we found statistically significant differences in exam performance typically favoring males over females and WA students over NALA students in all course sections. The average grade difference was 3.2% (0.41 SE) based on sex and 4.2% (0.43 SE) based on race/ethnicity in GC-I, and 1.3% (0.41 SE) based on sex and 1.8% (0.41 SE) based on race/ethnicity in GC-II. Nevertheless, as shown in Figs. 3 and 4, these differences seem to depend on the students' incoming academic preparation and the course instructor although the variability in the data limits the interpretation of these effects.

Overall, the cumulative effects of instructor, sex, and race/ethnicity can lead to estimated differences in average exam grades of up to eleven percentage points when comparing the performance of WA males in the highest performing course section and NALA females in the lowest performing course section for students with equivalent incoming academic preparation. The results of these analyses set the context in which the main investigation reported in this paper was conducted.

Research goals

Given the several shared curricular, instructional, and assessment components in the general chemistry classes taught by the main

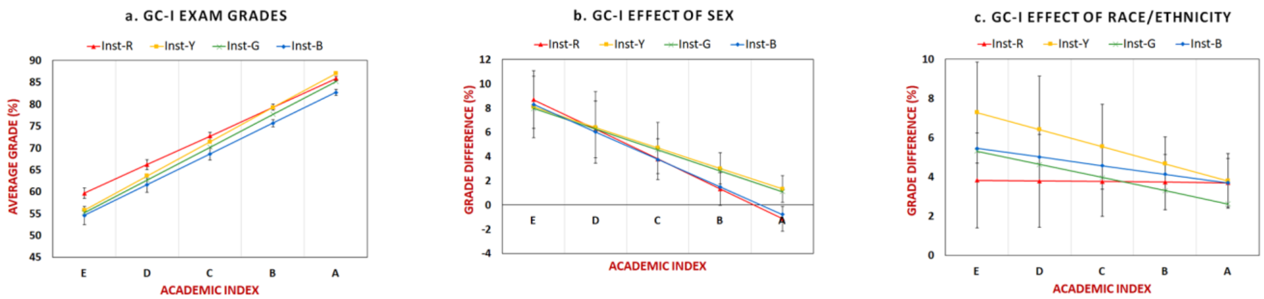


Fig. 4 Results from linear regression analyses for student performance in common exams represented as function of incoming preparation in GC-I course sections taught by instructors Inst-R, Inst-Y, Inst-G, and Inst-B. a) Estimated average grade in exams. b) Grade difference in estimated average exam grade based on sex (Grade Difference = average grade male students – average grade female students). c) Grade difference in estimated exam grade based on race/ethnicity (Grade Difference = average grade WA students – average grade NALA students). Standard error bars are shown for two instructors in each set to depict the variability in the data (standard errors have similar magnitudes in the other cases)

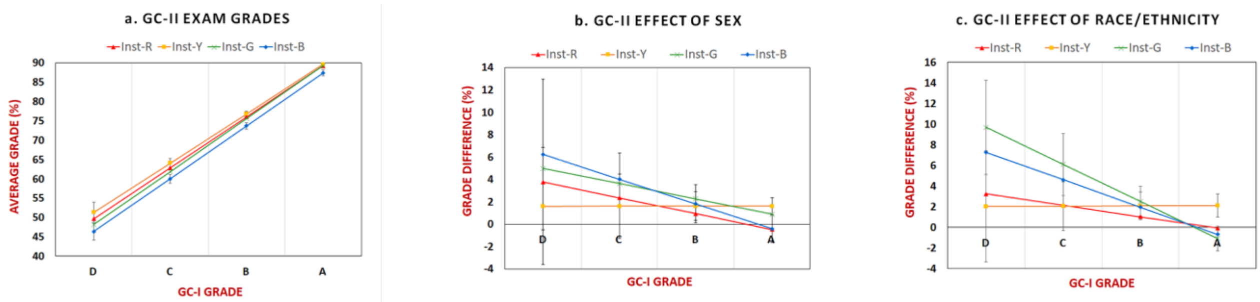


Fig. 5 Results from linear regression analyses for student performance in common exams represented as function of incoming preparation in GC-II course sections taught by instructors Inst-R, Inst-Y, Inst-G, and Inst-B. a) Estimated average grade in exams. b) Grade difference in estimated average exam grade based on sex (Grade Difference = average grade male students – average grade female students). c) Grade difference in estimated exam grade based on race/ethnicity (Grade Difference = average grade WA students – average grade NALA students). Standard error bars are shown for two instructors in each set to show the variability in the data (standard errors have similar magnitudes in the other cases).

instructors, we were interested in characterizing differences in their intended and enacted teaching practices that could provide insights into the observed differential performance of diverse groups of students in the common exams. Specifically, we explored differences in the relationships that the instructors sought and acted to build with intention in their classrooms based on the intentional-relational model introduced earlier. Recognizing the diverse, complex, and interconnected factors that affect student performance, our goal was not to identify specific causes for differential student achievements but rather to develop a better understanding of differences in instructors' decisions and actions that may affect academic outcomes. Our goal was neither to evaluate the quality of instruction nor to identify factors that may explain observed differences in instructors' intentions and actions (e.g., prior teaching experience, teaching, and learning beliefs). Rather, we sought to characterize instructors' practices from an intentional-relational perspective to gain insight into educational relationships that may affect student performance.

Data collection

Data for this main study was collected via individual semi-structured interviews with the four general chemistry instructors (labeled Inst-R, Inst-Y, Inst-G, and Inst-B in this paper), and observations of their teaching. The interviews included four sets of questions in the areas of planning for instruction, instruction in the classroom, support outside the classroom, and the uniqueness of their teaching approach. The interview protocol is included in Appendix A. A minimum of three observations were conducted in each of the instructors' classrooms during a spring semester in which all instructors were teaching GC-II. Fig.6 depicts the occurrence of each class observation in relation to the individual interview. Each observation was carried out for the entire duration of the lesson (50 to 75 minutes depending on the section observed). Detailed field notes were taken during each observation focused on describing the nature and sequence of the teachers' actions, their interactions with students and physical and human resources (e.g., instructional teams) in the classroom, as well as specific features of the teachers' discourse during the different parts of the lesson (e.g., lecture, in-class activities, whole-class discussions). The observed classes were not videotaped or recorded. All instructors consented to participate in the study as approved by the Institutional Review Board (IRB 1409498345).

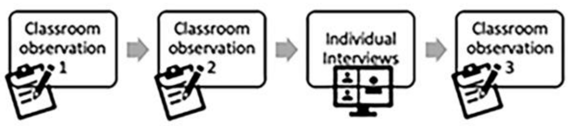


Fig. 6 Data collection sequence.

Data analysis

Individual interviews were transcribed and qualitatively analyzed using the intentional-relational model introduced in this paper to guide the analysis. Both interview transcripts and classroom observation field notes for each entire class session were segmented into episodes where instructors expressed an idea, described a decision, or enacted an action that was indicative of intentionality; that is, suggestive of deliberate and purposeful planning and decision-making to achieve a learning objective or meet the learning needs of students. Intentionality in the interviews was inferred from responses that suggested thoughtful reflection to achieve desired goals (e.g., describing a strategy to increase student engagement in the classroom, pointing to resources that they purposefully develop to foster student understanding). Intentionality in the classroom was inferred from explicit actions taken by the instructors (e.g., communicating with a learning assistant, using a response system to implement formative assessment, using students' ideas to build an explanation), as well as by aspects of the course they verbally emphasized or focused on (e.g., connecting a chemical concept to a relevant issue or phenomenon, providing a explicit strategy to solve a problem) that suggested purposeful behavior to achieve a goal.

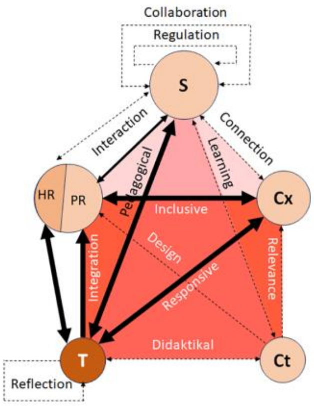
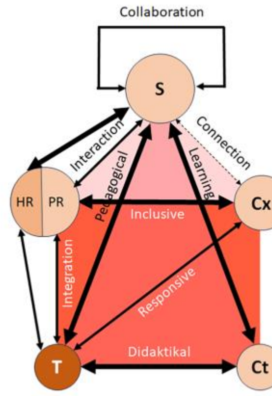
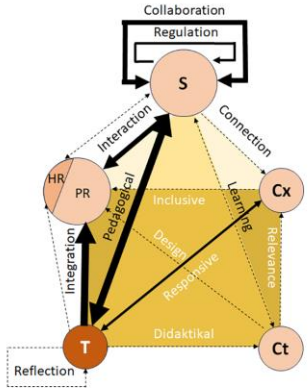
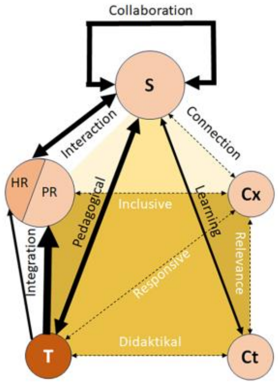
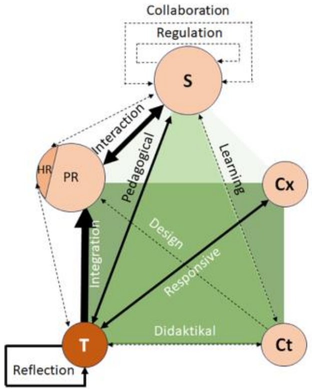
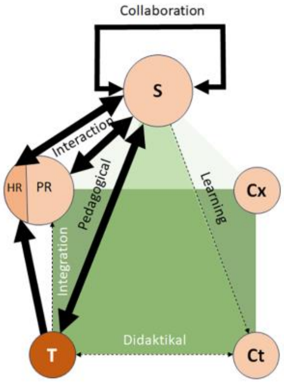
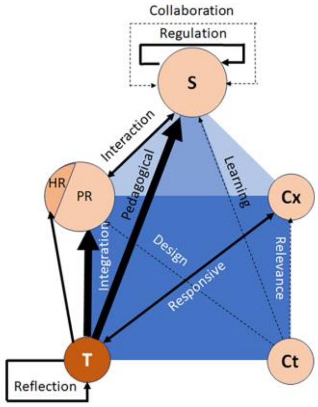
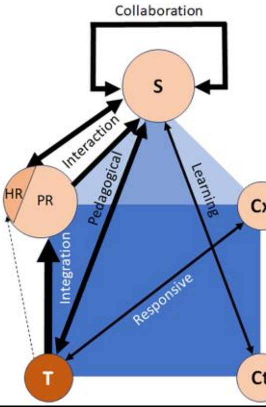
As illustrated in Table 2, each interview or field note segment was assigned a code or set of codes indicative of the type of components mentioned or acted on by the instructor (students, teacher, resources, content, context) and the relationships that the instructor intended to build, along with arrows showing the direction of the identified relation: unidirectional if only one of the two components seemed to drive or engage in the relationship or bidirectional if both components were involved. The initial segmentation and coding of each interview and classroom observation were carried out by the first author of this study, who then shared the analysis with the second author. This latter author reviewed corresponding codes, marked disagreements, and met with the first author to resolve all discrepancies via mutual agreement. Initially, discrepancies were related to differences in conceptualization of the relationships in the didaktik pyramid in Fig. 3 (e,g., what differentiates a pedagogical from a didaktikal intention, or an inclusive versus a responsive action). These discussions led to a refinement in the definitions of each of these relationships and the application of codes. Given that interview and observation episodes often reflected intentionality in building different relationships in the didaktik pyramid, discussions in subsequent cycles of analysis mostly centered on ensuring agreement in the number and types of codes assigned to a given segment. Additional examples of coded interview episodes and classroom events/actions representative of the different relationships that participating instructors emphasized are included in Appendix B.

Once all coding was completed, the frequencies of codes corresponding to each type of component and relationship were evaluated to determine their relative weight (percentage) in each instructor's verbalized intentions during the interviews and observed actions in the classroom. We used these relative weights to build the visual representations included in Table 3. Components mentioned with a frequency less than 20% were represented using circles with the same size as the "teacher" circle; components mentioned with a frequency between 20% and 30% were drawn using a circle of intermediate size, while components mentioned with a frequency larger than 30% were represented with a large circle. Similarly, arrows with different widths were drawn based on the relative frequency of the relationships inferred during the analysis: (1) 1 pt dotted lines were used to identify emergent intentional relations (0-5%); (2) 3 pt solid lines were indicative average intentional relations (5-10%); (3) 6 pt solid lines represented medium-high intentional relations (10-20%), and (4) 9 pt solid lines were used for high intentional relations (>20%). Finally, we used bidirectional arrows when 50% or more of the relationships identified during the analysis were coded as shaped or influenced by both components; we used unidirectional arrows to represent relationships mostly determined by one component. As can be seen in Table 3, we separated resources into physical resources (PR) and human

Table 2 Examples of codes assigned to different interview episodes. We highlight in bold and different color key elements in the interview transcripts that point to and led to the identification of the different components and relationships associated with each episode.

Example 1 *The instructor describes how students in the classroom are included as part of the instructional team in which the instructor, learning assistants, and all students are included and collaborate to support each other (pointing to a bidirectional relationship built by instructors and students).*	**Component**	**Relationship**	**Directionality**
"*It really resonated with them, and I think that just little way of* ***including them*** *in the* ***team*** *and making them feel* ***we're all part*** *of the* ***team****, and* ***we all serve a role****, and they are the most important role, that just really changed a lot about the* ***dynamic in the classroom*** *very much. So, I mean* ***I have these students****,* ***they'll come to me*** *at the end of the semester and have created a team shirt and then they'll sell it on like custom ink for people to buy separate I had a mom reach out to me and say I bought team shirts for the whole family team "Int- R" forever and it's just these little things go so far with just* ***their feeling of inclusion and support***" (Ints-R, interview)	Resources (HR) Context	Inclusive	←→
	Resources (HR) Teacher	Integration	←→
	Resources (HR) Students	Interaction	←→
Example 2 *The instructor describes actions taken to help students build connections between chemistry content and real-life contexts. The instructor focuses on the actions they individually take (what they say, what they ask) to accomplish their goals without active involvement of the students (unidirectional relationship).*	**Component**	**Relationship**	**Directionality**
"*I mean, I always offer that if they have questions* ***about stuff from lab****, to ask, and sometimes when there's something particularly challenging with lab they'll ask me. But now I probably don't do a great job of doing like thinking about things in lab I particularly with acids and bases,* ***I really try to get them to think about what you would do if you spilled this on yourself.*** *But you know just to get some perspective that's one of my introductory activities with acids and bases is like,* ***if you spilled acid on yourself what would you do****, and you know,* ***to get them to start thinking*** *about what are the* ***differences between types of acids and in terms of their strengths, but also their concentrations*** *and then* ***I asked them*** *like, so* ***if you spilled hydrochloric acid on yourself what would you do?*** *Would you call 911?* ***If you spilled lemon juice on yourself****, would you call 911?*" (Inst-Y, interview)	Content Context	Relevance	→
	Student Context	Connection	→

Table 3. Visual representations of relationships built by the four instructors as inferred from individual interviews and classroom observations in GC-II.

<table>
<tr><th>Instructor</th><th>Interview</th><th>Observation</th></tr>
<tr><td>Inst-R</td><td>
</td><td>
</td></tr>
<tr><td>Inst-Y</td><td>
</td><td>
</td></tr>
<tr><td>Inst-G</td><td>
</td><td>
</td></tr>
<tr><td>Inst-B</td><td>
</td><td>
</td></tr>
</table>

resources (HR) to better characterize the types of relationships built by different instructors. Some relationships involving resources are frequently bidirectional, like the Interaction of students with resources typically affected by characteristics of both components. Other relationships are frequently unidirectional like the Design of resources mostly determined by the nature of the content. Collaborative relationships were always coded as bidirectional (shaped by people in interaction), while we did not assign directionality to relationships involving only one component (Regulation, Reflection).

Results

Our analysis based on the intentional-relational model based on the didaktik pyramid in Fig. 3 allowed us to uncover similarities and differences in the relationships that different instructors sought to (during the interview) and seemed to (during the observations) build with intentionality in their classrooms. As summarized in Table 3, nine relationships out of the thirteen highlighted in our model were identified in the intentions expressed by all instructors during either the interviews or inferred from their actions in the classroom. Only a few of the relationships were not identified in the analysis of data from Inst-G (connection, inclusive, relevance) and Inst-B (didaktikal, connection, inclusive). There were, however, major differences in the frequency with which the various relationships manifested in each of the instructor's expressed ideas and actions, as well as in the directionality and characteristics of these relations.

Emphasis on students and resources

Of the five core components in the didaktikal pyramid in Fig. 3, two of them, students and resources, served as nodes for the majority of the relationships that the four instructors highlighted and built more explicitly in their classrooms. Over 70% of all components mentioned during any of the interviews corresponded to these two categories. The only instructor for whom a third component, context, had a medium presence in the data was Inst-R. As can be seen in the representations included in Table 3, the most salient relationships built by most instructors were associated with the left-side triangle in the pyramid formed by the three components teacher-resources-student, particularly the pedagogical (student-teacher) and integration (teacher-resources) relationships.

All instructors expressed interest and manifested care in helping students succeed and develop as learners beyond acquiring content knowledge (pedagogical relationship), but while instructors Inst-R, Inst-Y, and Inst-G often talked about their interest in empowering students, connecting with them on a more personal level, or engaging in dialogue to address needs (bidirectional relationship), Inst-B frequently took a more authoritative stance describing suggestions or recommendations given to students (in a unidirectional manner) to foster their learning or improve their performance (Scott, *et al.*, 2006). The following interview excerpts illustrate these contrasting approaches:

> "*So, if there's a group so if there's a group that's struggling, you know, my most common response is to go and sit down with them and say 'hey what's going on here?' And give them an opportunity to say 'I have no idea how to start this.' I'll sit down with them and I never start with just 'what questions do you have?' I kind of tend to start with, 'hi how are we doing today?' And, and then kind of more organically, let them open up and say, like, I have no idea how to start this.*". (Inst-Y)

> "*And, again that's just something that I bring up in class as I don't want to address students individually, but I would say it, in a very polite way to the class to stress the importance of engagement. That it is through group interactions, and explaining to another person, that you learn. And I say that to the class all the time*." (Inst-B)

In these representative examples, Inst-Y describes how they seek to connect to students on a more personal level and engage in dialog while exploring the difficulties students may have with the course content. In contrast, Inst-B often described the comments and suggestions that they made to their students to improve their learning. This more authoritative approach to guiding and supporting students, strongly based on providing guidance and direction on what to do without active engagement and dialog with the learners, is reflected in the larger number of unidirectional relationships identified in the didaktik pyramid for Inst-B in Table 3.

All instructors also emphasized the importance of providing resources to students to support their learning (integration relationship in the figures in Table 3). Resources, mainly physical resources and to a lesser extent human resources, played a major role as mediators of learning between each instructor and their students. As illustrated by the following interview excerpt, all instructors highlighted the design (content-resources relationship) and integration (teacher-resources relationship) of a variety of physical resources (PR) such as videos, class notes, past exams, and prep quizzes to help students better prepare for class or exams:

> *"I mean I just make them [videos] as I think about the content. So for them, I have these videos, that give them an idea about what we'll be discussing, and then, yeah, for example, this is just before the exam. What I did was I put all the things together like we do 1, 2, 3 and six, and then I asked them to use them to review for the upcoming exam." (Inst-G)*

The relationships related to the design and integration of physical resources were mostly unidirectional as the creation of support materials and their integration into the course was mostly informed by the instructors' beliefs and perceived needs of their students with little input from how students were engaging with those resources.

Inst-R was distinctive for the emphasis expressed and demonstrated in the classroom on integrating human resources (HR) to foster student learning inside and outside class. This instructor invests considerable time and effort in building and working with a large instructional team comprised of dozens of learning assistants (LAs). Although all instructors rely on LAs to support collaborative group work in the classroom, Instr-R has built a technological infrastructure that allows the instructor to quickly communicate with team members in the classroom, gather feedback on student performance during in-class activities, and adjust their teaching on the fly based on the input received:

"And so, this Mike project allows for really rapid communication, so I can help maybe clarify task instructions a little bit or give a few hints if the class is having a difficult time coming up with an answer. So that's the sort of thing that the instructional team will communicate with me". (Inst-R)

Inst-R's instructional team also provides support to students outside the classroom by offering office hours and managing a discussion platform where students pose questions and interact with each other and the LAs. This instructor was the only one who explicitly mentioned using formative feedback from LAs in the classroom to plan for instruction and adjust their teaching in real-time.

All instructors valued not only gathering and providing resources for students but also encouraging and structuring student interaction with these materials (student-resources relationship in the figures in Table 3). This was more evident in the interview and class observations for Inst-G, and somewhat less prevalent for Inst-B who seemed to more frequently point to the existence of physical and human resources without explicitly establishing structures or processes to drive and facilitate their use by the students.

Engaging students and facilitating learning

The front triangle in the pyramid in Fig.3 depicts the original didaktikal triangle, student-teacher-content, delineated by the pedagogical (student-teacher), learning (student-content), and didaktikal (teacher-content) relationships. During the interviews, instructors seldom talked about learning strategies or teaching approaches they used to engage students with specific chemistry content. They more often referred to more domain-general strategies that they utilized to facilitate student learning, as in the following example:

"*I slowly build up their knowledge, so that they can tackle similar problems at the intellectual so that's what I usually do*". (Inst-G)

The presence of structure or processes that actively engaged students with course content (learning relationship) was more prevalent in the classroom observations, particularly in the case of Inst-R who, for example, always initiated class by engaging students in an activity that required students to apply their prior knowledge (bell work). Inst-R and Inst-Y more systematically used whiteboards to make student work visible to their instructional teams, facilitating formative assessment. Three of the four instructors (Inst-R, Inst-Y, and Inst-G) more explicitly manifested their pedagogical content knowledge by referring to or using strategies in the classroom that facilitated student understanding of targeted ideas (didaktikal relationship). For instance, Inst-Y frequently used analogies to help students understand specific concepts and Inst-R provided heuristics to facilitate problem-solving and enhance student confidence and metacognition. The following interview excerpt illustrates this latter approach when making predictions about shifts in chemical equilibrium:

"So, if I give them a quick trick, they can feel more confident when predicting the shift. And then they can start thinking about Q versus K. And if they get the wrong shift or Q goes in the wrong direction, they're aware that they're wrong and they're thinking, because they have this trick to get the shift. And so, then they can go back and think about where their misconception is or where they're wrong in their thinking in terms of the why. So, all those little tricks are just there to give them a little bit more confidence." (Inst-R)

No evidence indicative of emphasis or intentionality in the didaktikal relationship was found in the data collected for Inst-B.

All instructors, both during the individual interviews and in the observations in classrooms, referred to and used structures and processes to foster student collaboration during group work (collaboration relationship). This relationship was particularly prevalent for Inst-Y, the only instructor who structured students' arrangement in groups in the classroom as described in the following interview excerpt:

"*So they get a total of three group assignments in my class, the second one, I take their first exam score, and I would take the lowest 50 students out of the bottom 20%. I put them at tables together, which might be controversial, but there is data and evidence out there that suggests that students that are paired with similar you know performance levels, it kind of helps to bring them out of their shells, and so what I would do and I didn't tell them, I always, yeah but those students I would put the closest to me and proximity. And I would make sure to have at least one preceptor split between their table and another so that they would get more specialized attention*." (Inst-Y)

Emphasis on student collaboration was least apparent for Inst-R who teaches in a 550-seat auditorium in which students mostly work in pairs or groups of three. Although the room is designed to facilitate interaction and collaboration compared to traditional lecture halls, group work is more diffuse in this environment.

During the interviews, all instructors also referred to opportunities they create for students to reflect on or evaluate their learning (regulation relationship). As illustrated by the following interview excerpt, these opportunities were often linked to physical resources designed to enhance study skills:

"So, I would have an exam review one week before the exam. And then they can take it an unlimited number of times and the goal is that they get to know what they're missing and need to study more. And now they have a week to fix the problems they have and adopt that for the future." (Inst-B)

This type of relationship was not explicitly present in the observations conducted in any of the classrooms.

Connections to context

The major differences in relationships emphasized or built by the different instructors in their classrooms corresponded to relations involving the "context" component. As shown in the different representations included in Table 3, the connection, inclusive, and relevance relationships were much less prevalent in the interviews and classroom observations for Inst-G and Inst-B than for Inst-R and Inst-Y (Inst-R manifested the strongest connections involving the context component). Although to different degrees, all instructors referred to aspects of their teaching that were indicative of responsiveness (teacher-context relationship) to students' ideas and learning challenges. For example, Inst-B described the use of formative assessment tools to regularly check on student understanding and use this information to make instructional decisions:

"So I use Socrative [personal response system] and I'll get a sense of where everybody is. With Socrative I can see like 'Oh, you know 78% of the students got this question right or only 30% of the students got this question right' so maybe this is something we should talk about." (Inst-Y)

This relationship was also present in the classroom observations for Inst-R, Inst-Y, and Inst-B. For instance, Inst-B noticed that students had difficulty working on a task and responded in the following manner:

"*After visiting several tables, the instructor presented the solution to the task, sharing and discussing the most common issues observed during the interactions*" (Inst- B).

In general, all instructors expressed or manifested responsiveness to students' ideas and learning difficulties (Gouvea and Appleby, 2022), but there were no clear indications of responsiveness in relation to the social and cultural capital that students bring into the classroom (Gay, 2002).

Inst-R and Inst-Y were the only ones who explicitly expressed or engaged in actions in their classrooms that indicated that they purposely adjusted their teaching and resources to facilitate learning and foster the success of all students (inclusive relationship). For example, Inst-R reflected constantly on course pace seeking to ensure that all students were progressing towards the learning goals:

"*I would say, usually what I'm thinking about in between, as I know, I need to move on to this material, but I want to make sure that the class has caught up on these main concepts before we move on, otherwise I'm going to leave a huge group behind.*" (Inst-R).

And made accommodations to facilitate student participation:

"I do the simultaneous running [in-person and Zoom] because the class is so big. I did have people reach out saying that they had immune problems and didn't feel comfortable coming to the large class and so that was why I decided to do the hybrid Zoom component. And I do have team members in the instructional team in the Zoom chat interacting with the students." (Inst-R)

Inst-Y created a variety of structures and processes to ensure that all students were aware of the work that needed to be completed to be prepared and succeed in the course:

"*After every class I email them. And at the top of the email are things that you need to be doing before the next class. I also provide them with very specific sections of the textbook that I want them to read before class*." (Inst-Y)

These two instructors also more frequently and explicitly referred to the importance of making course content relevant to the students in their classrooms (relevance relationships):

"*I am super invested in empowering my students with the ability to think independently. And I try to relate this to what their future career plans are because they're here to build a life for themselves, but they get so caught up in the " I have to get an A" and I don't want them to forget the big picture*." (Inst-R)

and meaningfully engaging students in thinking about issues of personal and professional interest (connection relationship):

"*I spend more time getting them to think about what their experiences have been with something before rather than maybe looking forward. Because I think trying to connect the content to something that they've already witnessed or experienced in their life might have more relevance to them than what their future career might be because they don't know what that looks like always*." (Inst-Y)

While Inst-G and Inst-B manifested the least explicit intentionality in building relationships associated with the "context" component, both were more explicit than the other two instructors in their reflections about teaching (teacher-teacher relationship). Inst-B was particularly reflective on different aspects of teaching practice, including issues related to assessment, student engagement, teaching in-person versus online, and balancing classroom time between providing information and engaging students in activity:

"*I noticed in the past that there's this balance… Like spending the whole day on activities and then the time just kind of goes away and you don't even get to the thermodynamic argument just stay on kinetics, so it has to be a balance. And so, I struggle with wanting to do too much and say too much*." (Inst-B)

Connection to student exam performance

Our analysis revealed similarities and differences in the relationships that the four instructors sought to build with intention in their classrooms. Major results are represented in the didaktik pyramids in Table 3 and the summary Table 4. In general, all instructors manifested a strong interest in helping students succeed in their studies and relied on a variety of educational resources designed and integrated into their courses to support student learning. They mostly differed in the extent to which they attended and responded to contextual issues, intentionally seeking to make content relevant to students, helping them build connections between their interests and the discipline, and adapting resources to create more inclusive learning environments.

From the perspective of our instructional-relational model, Inst-R demonstrated more balanced intentionality in all areas, followed by Inst-Y. These two instructors seemed to consider a broader set of factors while planning and implementing instruction than Inst-G and Inst-B, engaging with students at more diverse levels. Inst-G and Inst-B expressed intentions and actions mostly focused on relationships associated with the triad teacher-resources-students, although they more explicitly engaged in reflection about their practice. Inst-B expressed a strong and genuine interest in supporting student learning and designed and provided multiple physical resources to do so. This instructor's approach was, however, often more teacher-centered. Inst-G expressed less intentionality in contextual matters but manifested very strong pedagogical relationships with students, fostered collaboration in groups, and actively engaged students with a variety of physical and human resources in the classroom.

Table 4. Summary of relationships that instructors sought to build with intention. The number of cross marks is indicative of the relative frequency of the relationships inferred during the analysis of interview transcripts (I) and field notes from classroom observations (O): one cross mark for emergent intentional relations (0-5%); two cross marks for average intentional relations (5-10%); three cross marks for medium-high intentional relations (10-20%), and four cross marks for high intentional relations (>20%). Bidirectional arrows are used when 50% or more of the relationships identified during the analysis were coded as shaped or influenced by both components; otherwise, unidirectional arrows are drawn.

	Pedagogy (S-T)	Didaktics (T-Ct)	Learning (S-Ct)	Design (Ct-R)	Integrate (T-R)	Interact (S-R)	Responsive (T-Cx)	Relevance (Ct_Cx)	Connect (S-Cx)	Inclusive (R-Cx)	Regulate (S-S)	Collaborate (S-S)	Reflect (T-T)
Inst-R (I)	xxx ←→	x ←→	x ←→	x →	xxx ←→	xx ←→	xxx ←→	x →	x ←→	xxx ←→	x	x ←→	x
Inst-R (O)	xxx ←→	xxx ←→	xxx ←→		xx ←→	xxx ←→	xx ←→		x ←→	xxx ←→		xx ←→	
Inst-Y (I)	xxxx ←→	x →	x ←→	x →	xxxx →	xxx ←→	xx ←→	x →	x →	x →	xx	xxx	x
Inst-Y (O)	xxx ←→	x ←→	xx ←→		xxxx →	xxx ←→	x ←→	x ←→	x ←→	x ←→		xxx ←→	
Inst-G (I)	xx ←→	x ←→	x ←→	x →	xxxx →	xxx ←→	xx →				x	x ←→	xx
Inst-G (O)	xxxx ←→	x ←→	x →		xxxx →	xxxx ←→						xxx ←→	
Inst-B (I)	xxxx →		x →	x →	xxxx →	xx ←→	xx →	x →			xx	x ←→	xx
Inst-B (O)	xxx ←→		xx ←→		xxxx →	xxx ←→						xxx ←→	

Our analysis reveals the complexity of teaching activity, where a variety of decisions and actions may influence student engagement, performance, and achievement. In general, students enrolled in the classes of instructors that manifested intentionality in more areas and in more balanced ways exhibited stronger performance in common exams in both GC-I and GC-II. This suggests that intentionality in building a broader set of relationships linked to the "context" component in our model may benefit all students, particularly those with weaker incoming academic preparation for whom differences in performance tended to be larger between course sections. There are, however, marked differences in the didaktik pyramids of all instructors as represented in Table 3, suggesting that different balances in the relationships that instructors seek to build with intention, and diverse ways of enacting them, might be similarly impactful.

Analysis of the differential performance of students based on sex and race/ethnicity as shown in Figs. 4b, 4c, 5b, and 5c indicate that, in general, performance gaps seem to be smaller in GC-II in the classes taught by instructors with broader and more balanced intentionality, although there is great variability in the data. This may suggest that broader teacher intentionality that attends to contextual issues may also help reduce these differences and attenuate the strong impact that incoming academic preparation has on the magnitude of these gaps. This effect, however, is not consistent across courses, which indicates that other factors are at play and highlights the complexity of this issue. Our data suggests that acting with intention in different areas is not enough to systematically reduce or eliminate the observed gaps in exam performance which are present in all course sections. These results may be indicative of intrinsic biases in the design and use of high-stakes exams as assessment tools that are independent of the type of instruction.

Limitations

Our analysis of instructors' intentions was based on data collected through a single interview and a small number of observations in their classrooms during a single semester when all of them were teaching GC-II. These data provide a partial view of the complex system of decisions and actions that characterize these teachers' educational intentions and practices. A more in-depth characterization may be built using a case study approach, collecting a more diverse set of data over longer periods and different semesters. Instructors' decisions and actions may be sensitive to the content of the course they are teaching and the nature of the students with whom they work. From this perspective, our study should be considered exploratory of the potential use of the proposed intentional-relational model as a tool for characterizing instructors' intentional decisions and actions without the need for large and comprehensive pools of data.

As is the case for all qualitative studies, our analysis and interpretation of the data collected are affected by our knowledge, past experiences, and expectations; thus, our presentation and discussion of results may reflect our personal biases. Analyzing and comparing individual instructional practices using interpretive rather than evaluative lenses is challenging. We sought to objectively recognize and highlight the strengths and limitations in our participants' approaches to teaching as uncovered by our analytical model, but our personal beliefs about teaching and learning likely influenced what we noticed and the interpretations that we built.

We did not seek to identify causal links between instructors' decisions and actions and student performance in exams. Thus, our results do not provide insights into how and why specific instructional practices affect the observed academic results. We also recognize the limitations and lack of inclusivity of available performance data that conflates sex and gender, and race and ethnicity, as well as from grouping students from minoritized populations into one category. Disaggregated data in these binary categories shows great variability that limits the interpretation of differential teaching effects. This variability will likely increase with further disaggregation of the data into other subgroups.

In our study, we did not intend either to link observed differences in instructional approaches to instructors' prior preparation, experiences, or personal characteristics. We have purposely limited the amount of identifying information provided in the paper out of concern for potential misinterpretations of our data using evaluative lenses. We recognize that this decision may limit the insights that can be gained from our results about factors that affect instructional practices.

Implications and Conclusions

Teaching is a complex activity that demands paying attention to diverse components and relationships that affect the learning process and acting with intentionality to build and nurture those connections. The intentional-relational model proposed and used in our study makes explicit the major relationships that research suggests support the creation of productive learning environments (Hopmann, 2007; Rezat and Sträßer, 2012; Paguyo*, et al.*, 2022; Artze-Vega*, et al.*, 2023). These relationships are interconnected but, in our analysis, we sought to reduce such a complexity by characterizing them as independent relations. That allowed us to uncover major similarities and differences in the teaching intentions and practices of the instructors involved in our study. We contend then that adopting an intentional-relational framework when looking into teaching practices may be useful in identifying strengths and areas for improvement. From this perspective, our works may inform the development of professional development programs for college instructors and the design of rubrics and strategies for providing formative feedback to improve their practice.

Our analysis revealed, for example, that all participating instructors were intentionally responsive to the ideas and learning challenges of their students (Gouvea and Appleby, 2022). Nevertheless, none of them manifested significant intentions in responding to the social and cultural capital that students bring into the classroom and in using these resources to engage students and foster understanding (Gay, 2002). These instructors would thus benefit from feedback and access to professional development resources that support the creation of more culturally responsive learning environments. Although all instructors sought to actively engage students in the learning process and manifested strong pedagogical and integration intentions, there was variation in the extent to which they adopted more authoritative versus more dialogical stances (Scott*, et al.*, 2006). Recognition of these differences can support the design of interventions that help instructors reflect on their approaches and modify their practices.

Evaluation of college teaching has traditionally relied on student ratings and feedback and judgments by peers based on the characterization of observable instructional actions in the classroom (National Academies of Sciences, 2020). The limitations of these approaches have been the subject of reflection and discussion in recent years, resulting in various initiatives to transform teaching evaluations in disciplines (Andrews*, et al.*, 2020). These initiatives provide general criteria and guidelines focused on the analysis of teaching goals, practices, student outcomes, classroom climate, and teacher reflection and growth. Teaching observation protocols, such as COPUS (Smith*, et al.*, 2013), RTOP (Sawada*, et al.*, 2002), and others (Asgari*, et al.*, 2021) provide a detailed characterization of teachers' and students' actions in classrooms. These different instruments tend to make explicit the behaviors in which the instructors engage, but not their intentions in terms of building relationships between core educational components. Enriching these measures from an intentional-relational perspective could help better identify strengths and areas in need of improvement to enrich students' learning experiences.

The results of our investigation also point to the need for research that explores how and why college instructors' intentions, decisions, and actions affect students' performance in diverse aspects of a course. Existing research indicates that the opportunities that instructors create for students to meaningfully engage with the course content have a significant impact on their performance (Daubenmire*, et al.*, 2015). In our study, all instructors created active and interactive learning environments and genuinely sought to provide their students with resources to succeed. Despite their efforts, performance gaps in exams were present between course sections and significant differences related to sex and race/ethnicity persisted in all cases. If we are to create inclusive learning environments that create equitable learning opportunities for all students, we need to better understand how specific classroom structures and processes affect student outcomes. We also need to reflect on how to support instructors to foster meaningful learning by not only considering and responding to cognitive challenges but also by paying attention to sociocultural aspects and tapping into students' social and cultural capitals.

Due to the interconnected and interdependent nature of the different relationships highlighted in the didaktik pyramid in Fig. 3, their identification and characterization in independent ways, as approached in this study, is sometimes challenging. That may impose limitations in the application of our intentional-relational model as a tool in the analysis of teacher thinking and practice. Nevertheless, we believe our model helps make explicit the complexity of student-centered teaching and its connection to student performance.

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

This work was supported by the National Science Foundation – Improving Undergraduate STEM Education, under Grant #DUE-1626531.

References

Anderson T., (2004), Towards a theory of online learning in Anderson T. (ed.), *The theory and practice of online learning* Edmonton, CA: AU Press, pp. 45-74.

Andrews S. E., Keating J., Corbo J. C., Mark G., Reinholz D. L. and Finkelstein N., (2020), Transforming teaching evaluation in disciplines: A model and case study of departmental change, in White K., Beach A., Finkelstein N., Henderson C., Simkins S., Slakey L., Stains M., Weaver G. and Whitehead L. (eds.), *Transforming institutions: Accelerating systemic change in higher education,* Pressbooks, ch. 13, pp. 189-204.

Artze-Vega I., Darby F., Dewsbury B. and Imad M., (2023), *The norton guide to equity-minded teaching*, New York: W. W. Norton.

Asgari M., Miles A. M., Lisboa M. S. and Sarvary M. A., (2021), Copus, portaal, or dart? Classroom observation tool comparison from the instructor user's perspective, *Front. Educ.*, **6**.

Ausubel D. P., (2000), *The acquisition and retention of knowledge*, Dordrecht: Kluwer.

Becker N., Rasmussen C., Sweeney G., Wawro M., Towns M. and Cole R., (2013), Reasoning using particulate nature of matter: An example of a sociochemical norm in a university-level physical chemistry class, *Chem. Educ. Res. Pract.*, **14**, 81-94.

Biggs J. B., (1993), From theory to practice: A cognitive systems approach, *High. Educ. Res. Dev.*, **12**, 73-85.

Chi M. T. H. and Wylie R., (2014), The icap framework: Linking cognitive engagement to active learning outcomes, *Educ. Psychol.*, **49**, 219-243.

Daubenmire P. L., Bunce D. M., Draus C., Frazier M., Gessell A. and van Opstal M. T., (2015), During pogil implementation the professor still makes a difference, *J. Coll. Sci. Teach.*, **44**, 72-81.

DeLozier S. J. and Rhodes M. G., (2017), Flipped classrooms: A review of key ideas and recommendations for practice, *Educ. Psychol. Rev.*, **29**, 141-151.

Dewsbury B. and Brame C. J., (2019), Inclusive teaching, *CBE Life Sci. Educ.*, **18**, fe2.

Eberlein T., Kampmeier J., Minderhout V., Moog R. S., Platt T., Varma-Nelson P. and White H. B., (2008), Pedagogies of engagement in science: A comparison of pbl, pogil, and pltl, *Biochem. Mol. Bio. Educ.*, **36**, 262-273.

Eddy S. L. and Hogan K. A., (2014), Getting under the hood: How and for whom does increasing course structure work?, *CBE Life Sci Educ*, **13**, 453-468.

Engeström Y., (1987), *Learning by expanding. An activity-theoretical approach to developmental research.* , Helsinki: Orienta-Konsultit Oy.

Fitzgerald M. S. and Palincsar A. S., (2019), Teaching practices that support student sensemaking across grades and disciplines: A conceptual review, *Rev. Res. Educ.*, **43**, 227-248.

Freeman S., Eddy S. L., McDonough M., Smith M. K., Okoroafor N., Jordt H. and Wenderoth M. P., (2014), Active learning increases student performance in science, engineering, and mathematics, *PNAS*, **111**, 8410-8415.

Freeman S., Haak D. and Wenderoth M. P., (2011), Increased course structure improves performance in introductory biology, *CBE Life Sci Educ*, **10**, 175-186.

Friesen N., (2017), The pedagogical relation past and present: Experience, subjectivity and failure, *J. Curr. Stud.*, **49**, 743-756.

Gay G., (2002), Preparing for culturally responsive teaching, *J. Teach, Educ.*, **53**, 106-116.

Geiger V., (2014), The role of social aspects of teaching and learning in transforming mathematical activity: Tools, tasks, individuals and learning communities, in Rezat S., Hattermann M. and Peter-Koop A. (eds.), *Transformation - a fundamental idea of mathematics education*, New York, NY: Springer New York, pp. 203-222.

Gillies R. M., (2016), Dialogic interactions in the cooperative classroom, *Int. J. Educ. Res.*, **76**, 178-189.

Gouvea J. and Appleby L., (2022), Expanding research on responsive teaching, *CBE Life Sci. Educ.*, **21**, fe2.

Harris R. B., Mack M. R., Bryant J., Theobald E. J. and Freeman S., (2020), Reducing achievement gaps in undergraduate general chemistry could lift underrepresented students into a "hyperpersistent zone", *Sci. Adv.*, **6**, eaaz5687.

Hartman J. R., Nelson E. A. and Kirschner P. A., (2022), Improving student success in chemistry through cognitive science, *Found. Chem.*, **24**, 239-261.

Hodges L. C., (2018), Contemporary issues in group learning in undergraduate science classrooms: A perspective from student engagement, *CBE Life Sci. Educ.*, **17**, es3.

Hopmann S., (2007), Restrained teaching: The common core of didaktik, *Eur. Educ. Res. J.*, **6**, 109-124.

Hudson B., (2007), Comparing different traditions of teaching and learning: What can we learn about teaching and learning?, *Eur. Educ. Res. J.*, **6**, 135-146.

Kilderry A., (2015), Intentional pedagogies: Insights from the past, *Australas. J. Early Child.*, **40**, 20-28.

King D., (2012), New perspectives on context-based chemistry education: Using a dialectical sociocultural approach to view teaching and learning, *Stud. Sci. Educ.*, **48**, 51-87.

Lawrie G., Marquis E., Fuller E., Newman T., Qiu M., Nomikoudis M., Roelofs F. and Van Dam L., (2017), Moving towards inclusive learning and teaching: A synthesis of recent literature, *Teach. Learn. Inq.*, **5**, 9-21.

Loewenberg Ball D., Thames M. H. and Phelps G., (2008), Content knowledge for teaching:What makes it special?, *J. Teach, Educ.*, **59**, 389-407.

Lombardi D., Shipley T. F., Bailey J. M., Bretones P. S., Prather E. E., Ballen C. J., Knight J. K., Smith M. K., Stowe R. L., Cooper M. M., Prince M., Atit K., Uttal D. H., LaDue N. D., McNeal P. M., Ryker K., St. John K., van der Hoeven Kraft K. J. and Docktor J. L., (2021), The curious construct of active learning, *Psychol. Sci. Public Interest*, **22**, 8-43.

Mintzes J. J. and Walter E. M. (eds.), (2021), Active learning in college science: The case for evidence-based practice, Switzerland: Springer Cham.

Moll L. C., Amanti C., Neff D. and Gonzalez N., (1992), Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms, *Theory Into Practice*, **31**, 132-141.

Moon A., Stanford C., Cole R. and Towns M., (2017), Decentering: A characteristic of effective student–student discourse in inquiry-oriented physical chemistry classrooms, *J. Chem. Educ.*, **94**, 829-836.

National Academies of Sciences, Engineering, and Medicine, (2020), *Recognizing and evaluating science teaching in higher education: Proceedings of a workshop–in brief*, Washington, DC: The National Academies Press.

National Research Council, (2012), *Discipline-based education research: Understanding and improving learning in undergraduate science and engineering*, Washington, DC: The National Academies Press.

National Research Council, (2015), *Reaching students: What research says about effective instruction in undergraduate science and engineering*, Washington, DC: The National Academies Press.

Nennig H. T., States N. E., Macrie-Shuck M., Fateh S., Gunes Z. D. K., Cole R., Rushton G. T., Shah L. and Talanquer V., (2023), Exploring social and cognitive engagement in small groups through a community of learners (col) lens, *Chem. Educ. Res. Pract.*

Paguyo C. H., Sponsler L. E. and Iturbe-LaGrave V., (2022), Centering theories of learning to design humanizing pedagogies and inclusive assessments, *New Dir. Stud, Serv.*, **2022**, 175-183.

Reid J. W., Kirbulut Gunes Z. D., Fateh S., Fatima A., Macrie-Shuck M., Nennig H. T., Quintanilla F., States N. E., Syed A., Cole R., Rushton G. T., Shah L. and Talanquer V., (2022), Investigating patterns of student engagement during collaborative activities in undergraduate chemistry courses, *Chem. Educ. Res. Pract.*, **23**, 173-188.

Rezat S. and Sträßer R., (2012), From the didactical triangle to the socio-didactical tetrahedron: Artifacts as fundamental constituents of the didactical situation, *ZDM*, **44**, 641-651.

Roberson B. and Franchini B., (2014), Effective task design for the tbl classroom, *J. Excell. Coll. Teach.*, **25**, 275-302.

Sawada D., Piburn M. D., Judson E., Turley J., Falconer K., Benford R. and Bloom I., (2002), Measuring reform practices in science and mathematics classrooms: The reformed teaching observation protocol, *Sch. Sci. Math.*, **102**, 245-253.

Scherr R. E. and Hammer D., (2009), Student behavior and epistemological framing: Examples from collaborative active-learning activities in physics, *Cogn. Instr.*, **27**, 147-174.

Schneider M. and Preckel F., (2017), Variables associated with achievement in higher education: A systematic review of meta-analyses, *Psychol. Bull.*, **143**, 565-600.

Schon D., (1983), *The reflective practitioner. How professionals think in action*, London: Temple Smith.

Scott P. H., Mortimer E. F. and Aguiar O. G., (2006), The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons, *Sci. Educ.*, **90**, 605-631.

Seery M. K., (2015), Flipped learning in higher education chemistry: Emerging trends and potential directions, *Chem. Educ. Res. Pract.*, **16**, 758-768.

Smith K. A., Sheppard S. D., Johnson D. W. and Johnson R. T., (2005), Pedagogies of engagement: Classroom-based practices, *J. Eng. Educ.*, **94**, 87-101.

Smith M. K., Jones, Francis H. M., Gilbert S. L. and Wieman C. E., (2013), The classroom observation protocol for undergraduate stem (copus): A new instrument to characterize university stem classroom practices, *CBE Life Sci. Educ.*, **12**, 618-627.

Stains M. and Vickrey T., (2017), Fidelity of implementation: An overlooked yet critical construct to establish effectiveness of evidence-based instructional practices, *CBE Life Sci. Educ.*, **16**, rm1.

Stuckey M., Hofstein A., Mamlok-Naaman R. and Eilks I., (2013), The meaning of 'relevance' in science education and its implications for the science curriculum, *Stud. Sci. Educ.*, **49**, 1-34.

Talanquer V. and Pollard J., (2010), Let's teach how we think instead of what we know, *Chem. Educ. Res. Pract.*, **11**, 74-83.

Talanquer V. and Pollard J., (2017), Reforming a large foundational course: Successes and challenges, *J. Chem. Educ.*, **94**, 1844-1851.

Tall D., (1986), Using the computer as an environment for building and testing mathematical concepts: A tribute to richard skemp, in *Papers in honour of richard skemp*, Warwick: University of Warwick, pp. 21-36.

Tashiro J. and Talanquer V., (2021), Exploring inequities in a traditional and a reformed general chemistry course, *J. Chem. Educ.*, **98**, 3680-3692.

Theobald E. J., Hill M. J., Tran E., Agrawal S., Arroyo E. N., Behling S., Chambwe N., Cintrón D. L., Cooper J. D., Dunster G., Grummer J. A., Hennessey K., Hsiao J., Iranon N., Jones L., Jordt H., Keller M., Lacey M. E., Littlefield C. E., Lowe A., Newman S., Okolo V., Olroyd S., Peecook B. R., Pickett S. B., Slager D. L., Caviedes-Solis I. W., Stanchak K. E., Sundaravardan V., Valdebenito C., Williams C. R., Zinsli K. and Freeman S., (2020), Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math, *PNAS*, **117**, 6476-6483.

Van den Bossche P., Gijselaers W., Segers M., Woltjer G. and Kirschner P., (2011), Team learning: Building shared mental models, *Instruc. Sci.*, **39**, 283-301.

Wilson-Kennedy Z. S., Payton-Stewart F. and Winfield L. L., (2020), Toward intentional diversity, equity, and respect in chemistry research and practice, *J. Chem. Educ.*, **97**, 2041-2044.

Zimmerman B. J., (2008), Investigating self-regulation and motivation: Historical background, methodological developments, and future prospects, *Am. Educ. Res. J.*, **45**, 166-183.

Appendix A. Interview protocol

General information

1. Could you tell us your name and area of expertise?
2. How long have you been teaching at the college level?
3. How long have you been teaching _____ class?

Planning for instruction

4. When planning a class (or lesson), what specific ideas or strategies guide your approach to preparing the class? In general terms, what do you do or think about to build a lesson that facilitates or motivates student engagement with the content and will foster their understanding?
5. What do you see as critical structural components of your lessons that help students to develop understanding of the concepts or ideas that you want to target?

Instruction in the classroom

6. When teaching a class (or lesson), what specific ideas or strategies do you use that facilitate or motivate student engagement with the content and foster their understanding?
7. What structures or resources or strategies do you use in the classroom to engage, support, facilitate, foster student understanding (explore use of classroom layout, learning assistants, physical resources, technology, etc.)

Support outside the classroom

8. When teaching the course, what specific structures or resources or strategies do you use that facilitate or motivate student engagement with the course activities:
   - What do you do to encourage work on homework?
   - What do you do to encourage reading the textbook or reviewing course content or prepare for class?
   - What do you do to encourage work on lab?
   - What do you do to encourage and facilitate exam preparation/success?
   - What other areas do you purposely target and why?

Uniqueness

9. In your perspective, what types of structures, activities, or approaches do you use that make your approach to teaching unique and effective at fostering student engagement with the content, foster understanding, and improve student performance in the course?

Appendix B. Coding examples

We present in Table 1B excerpts from individual interviews and classroom observations that illustrate the assignation of codes used in our study. Several relationship codes could be applied to a given episode, but we highlight only one of them.

Table 1B. Examples of relationships in the intentional-relational model identified in the analysis of interviews and classroom observations.

Relationship	Interview Episode	Observation Event/Action
(S-T) Pedagogical	*"I try to be more of a butterfly because I don't want to get trapped into a table. Obviously, that makes the time go away, so I try to be a butterfly and I answer questions from students, but then I need to go around and hear what others are doing."* (Inst-B)	The instructor uses positive reinforcement when listening to student responses. (Inst-Y)
(T-Ct) Didaktikal	"Based on what I listen in the classroom I try to do video notes. I mean, for example…I see that students struggle using line structures. So, I make a separate video where I show step by step how to build them." (Inst-G)	The instructor makes sure to present the reasoning behind the answer to the question posed (justifying a shift in chemical equilibrium). (Inst-R)
(S-Ct) Learning	*"When I am in the classroom, I tell them what I want them to know by the end of that lesson… And then, sometimes I present an example that is representative of what they should be able to do after the lecture so that they know the objective of the lesson."* (Inst-G)	The instructor does not only present her explanations to the specific topic. The instructor presents a generalization to show that students can use the strategy or reasoning in other situations or tasks. (Inst-Y)
(Ct-R) Design	*"I started making short videos. Just to maybe it started with like this activity in class was an absolute disaster and so I'm going to make a five-minute video where I walk through this activity and hopefully the students can watch this and get clarification."* (Inst-R)	-
(T-R) Integration	*"And sometimes I take the approach of I'm not the tutor in the classroom, I'm the manager of the classroom and so sometimes I will grab a preceptor and say, hey would you mind coming over here and helping them?"* (Inst-Y)	During the lesson, the instructor and team members walked around the classroom while students complete tasks (Inst-B)
(S-R) Interaction	*"So we have office hours, and then I would take the questions that were asked in office hours, and then I would work on them on a video and post it…so students who want to work out problems can come to office hours and students who want to talk about chemistry at 3 AM they can look at the video."* (Inst-B)	The lesson started with a quiz/task where students worked in groups while team members approached some tables and used the whiteboard to help students complete the task. (Inst-G)
(T-Cx) Responsive	*"I also have a subset of my learning team that's the polling team, so they do student driven polls and I get a lot of information from the student responses in there as well… My team puts them together and then my team organizes the results, and then I use a "Discord" channel and they'll give me the results in that discord channel. And so I can utilize those in conjunction with everything to kind of figure out the main confusions the best way that I can"* (Inst-R)	After visiting the tables, the instructor explained the solution to the task, sharing what was the most common problem detected within the groups (Inst-B)
(Ct-Cx) Relevance	*"I think about it, like we talked about medicines. You know, like we talk a lot when you're dealing on a consistent basis with painkillers. And you know where they exist on the spectrum of acids versus bases, so kind of that context, or that it matters you know whether it's likely to be absorbed or not in different parts of the body."* (Inst-Y)	The instructor tells students the utility of the chemical compound mentioned in the task. (Inst-Y)
(S-Cx) Connection	*"And all of that is the power of this chemistry class because also so many of them are saying I'm never going to use chemistry again, why do I care about this. Well, you should care about this, because I'll give real life examples, this is how straightening your hair works or this is how a Perm works if it intersects with the information. I'm just trying to teach you how to think so that whatever discipline you're going into"* (Inst-R)	Students worked collaboratively in an activity comparing the pH of two different solutions of well-known pharmaceutical drugs (Tylenol and Aspirin). (Inst-R)
(R-Cx) Inclusive	*"I feel like there's two main groups of students. There's those who have no idea where to start. That group just try to jump to this complex answer, and then they put themselves into a black hole where they just don't think they know anything anymore, because they just don't know how to organize the material. So, I help them to take a step back and organize what they have in a way that allows them to answer the questions."* (Inst-R)	The environment created by the instructor using a more informal language, jokes or telling personal stories to the students creates a relaxed environment, where students laugh and work. They seem to feel free to ask any question. (Inst-Y)
(S-S) Regulation	*"I ask my students to think about the questions they missed. And then, how to not to make the same mistakes again. I call this an exemplary reflection."* (Inst-G)	-
(S-S) Collaboration	*"I tried to instil a sense of grace and compassion with my students. I expect students to work in groups. I assign those groups and as a function of that I set up their group work with an attitude of nobody's perfect, we are all imperfect humans, nobody knows anything. And we have to understand that when we're walking in here perfection is not the expectation, but also that we don't know what anybody's been through in any given week month year lifetime."* (Inst-Y)	Students are engaged and discussing the tasks in small groups. (Inst-G)
(T-T) Reflection	*"If I had to self-evaluate the reason why students are being successful and engaged is because of the "Let's Think" activities. Students working on them and us providing that space and time."* (Inst-B)	-