Evolution: Education and Outreach

RESEARCH ARTICLE

Open Access

Critical relationships in managing students' emotional responses to science (and evolution) instruction

Lawrence C. Scharmann[1*] and Bette L. Grauer[2]

Abstract

Background: If an instructional environment that is conducive to learning generally requires the development of good student–teacher relationships, then a classroom atmosphere of trust is an especially important consideration when we engage students in the teaching and learning of evolution. Emotional scaffolding, therefore, is crucial to the successful teaching and learning of evolution. Quinlan (Coll Teach 64:101–111, 2016) refers to four key relationships necessary to construct this scaffolding—students with teachers being merely one of the four key relationships comprising a comprehensive emotional scaffolding—the others being students with subject matter, students with other students, and students with their developing selves. Our purpose here is to examine the types of student emotional responses that secondary science teachers reported as emerging in their science classes and categorize students' behavioral responses as being representative of the four key relationships, identified by Quinlan (Coll Teach 64:101–111, 2016), as necessary for promoting both enhanced learning and individual student growth.

Results: The results of this current study are highly encouraging in that respect. Each of the eight teachers were able to identify the development of each of the four key relationships identified by Quinlan as crucial for instructional success. In addition, where individual teacher profiles were statistically different than the aggregate profile across all eight teachers, it was due to a trade-off in emphasis of the development of one relationship in preference to another.

Conclusion: The most salient recommendations to manage emotional responses to evolution instruction are to: (1) Foster relationships that engage students in positive conversations; (2) Construct relationships in an appropriate sequence—Teacher–Student and Subject–Student first, followed by student–student and finally nurturing students with developing selves; (3) Use non-threatening assessments; and (4) Allow students to privately express their honest feelings about the science being learned.

Keywords: Critical relationships, Evolution education, Emotional responses

Background

> *Relationships between students and teachers are important in creating classroom atmospheres of trust and cooperation. Opening ourselves up to students requires us to be aware of our own emotions, to observe and interpret students' emotions, and to cope with students' feelings as they are expressed. All of these are demanding and important—if rarely acknowledged—aspects of teaching.*
>
> (Quinlan 2016, p. 105)

Quinlan (2016) argues persuasively that understanding and cultivating positive relationships between students and teachers is a crucial element in students' perceptions of the effectiveness of one's instruction. She further argues that the Teacher–Student relationship is but one

*Correspondence: lscharmann2@unl.edu
[1] Teaching, Learning, and Teacher Education, University of Nebraska-Lincoln, Lincoln, USA
Full list of author information is available at the end of the article

of four key relationships that need to be recognized and fostered to fully engage students as self-aware, active participants in their own learning—the other key relationships being between students and subject matter, other students, and with their developing selves. The historical roots of Quinlan's argument for establishing and fostering key relationships, can be directly traced to her academic lineage—Quinlan studied with Lee Shulman (Stanford University); Lee Shulman studied with Joseph J. Schwab (University of Chicago). Quinlan's work reflects and builds upon elements of both Schwab's and Shulman's influences.

Schwab was a prominent curriculum theorist for four decades (1930s to 1970s) and of consequential importance in the post-Sputnik revisions to biology curricula, specifically in collaboration with the Biological Sciences Curriculum Study (BSCS). Schwab also championed the use of peer discussion as an alternative to lecture in science courses. Schwab is best known, nonetheless, for his seminal *The Practical* (Schwab 1973), in which he identifies four commonplaces that should be simultaneously considered while constructing curriculum materials. These research-derived commonplaces are "needs of learners, needs of teachers, subject matter competence, and milieus." Schwab forcefully demonstrated that emphasis on one commonplace at the expense of the others or elimination of one or more commonplaces can have severe repercussions that negatively impact instructional effectiveness. Quinlan's key relationship of students with subject matter has direct connection to Schwab's commonplace of subject matter competence. In addition, Schwab's commonplaces of needs of students and milieus (i.e., descriptions of various social interactions that should occur in effective course instruction) have parallels with Quinlan's students with students and students with teacher relationships.

Schwab also directly influenced the delineation of disciplinary knowledge in Shulman's development of his conception of "pedagogical content knowledge" (PCK) (Shulman 1986). PCK develops and expands upon Schwab's commonplace of subject matter competence. Teachers in possession of greater PCK are able to spontaneously find analogies that connect subject matter to student interests or construct developmentally appropriate learning activities to meet the needs of novice learners; conversely, teachers with less PCK tend to favor memorization, rote learning, and the use of notetaking (James and Scharmann 2007).

What makes Quinlan's work compelling is both in the manner in which she embraces the influences of Schwab and Shulman and in having done so, focuses "… on discipline-sensitivity in teaching and learning and students' holistic development" (Quinlan 2020). In other words, she encourages using students' positive emotional responses engendered through the development of four key relationships to improve instructional practices.

If an instructional environment that is conducive to learning generally requires the development of good student–teacher relationships, then a classroom atmosphere of trust is an especially important consideration when we engage students in the teaching and learning of science—especially with respect to evolution (Bertka et al. 2019; Nelson et al. 2019; Scharmann 2018; Pobiner et al. 2018; Southerland and Scharmann 2013; Oliviera et al. 2011; Woods and Scharmann 2001). Winslow et al. (2011) argued further that when students perceive that their instructor lacks an emotional relationship with them, that it is almost a certainty that student apprehensions about learning evolution will be retained. Conversely, Winslow et al. also reported, that when students perceive the student–teacher relationship as one of trust and mutual respect, students are more willing to consider the viability of evolutionary concepts and thought processes. This latter assertion was more recently reinforced by Holt et al. (2019) in reporting that teachers (among others) must be perceived as positive role models that develop an atmosphere of trust and mutual respect. Without trust and mutual respect in the context of teaching evolution—according to Kampourakis (2014)—students are more likely to resist the study of evolution because they find evolutionary theory a rather counterintuitive idea.

Bertka et al. (2019) reported, nonetheless, that many biology teachers lacked the resource(s) necessary to engage students in discussing their cultural or religious concerns about evolution. As part of a larger research program (Bertka et al. 2019; Pobiner et al. 2018), Bertka et al. constructed a Cultural and Religious Sensitivity (CRS) teaching strategies resource to serve as a tool that could assist teachers in facilitating conversations about students' concerns. Students who participated in discussions that were guided by CRS instructional formats reported reduced tensions, an increased understanding of biological phenomena through the lens of evolution and came to conclude that their religious beliefs were not necessarily in conflict with learning evolution.

Scharmann and Butler (2015) reported similar findings when they used journaling as a non-threatening assessment tool in a community college nonmajors' biology course, to engage students in freely discussing their concerns, worries, or emotions about evolution. They found that students saw fewer conflicts between their religious values and evolution at the end compared to their views at the beginning of a semester of study in general biology. The majority of students voiced in their journal reflections that these fewer conflicts were a result of having the freedom to honestly report how they were feeling about the science they were learning and for being reinforced by their instructor for having done so. Scharmann (2018) followed up on this assertion of fewer concerns (about the study of evolution) resulting from the employment of non-threatening assessment practices. Non-threatening assessment, Scharmann noted, is one of four conditions necessary to ensure enhanced success in teaching a unit on evolution to nonmajors.

Despite the positive influences extolled above in recognizing students' emotional concerns as a natural instructional outcome to be integrated within instruction because it enhances the student–teacher relationship, science teachers tend to intentionally avoid the affective domain (Garritz 2010). What are the reasons for lack of interest and attention to the affective domain in science? One explanation is the traditional image of science as reason driven and free of emotion (Alsop and Watts 2003). Another reason is to avoid controversy and conflict with personal beliefs in topics such as evolution, geological time, climate change, and the origin of the universe (Scharmann 2005). A third reason is that educators consider emotions unreliable (Noddings 1996). Finally, educators have suggested that student interest in a topic would be maintained through participation in inquiry activities, and that appreciation of the topic would develop with continued study (Bybee et al. 2006; Krathwohl et al. 1964).

The affective domain, therefore, has been an understudied area in science education. Studies on student affect have focused on attitude and motivation (Garritz 2010; Klopfer 1976). However, as illustrated by Krathwohl's Affective Taxonomy, the affective domain encompasses multiple facets of human feelings, values, and associated behavioral responses (Krathwohl et al. 1964). Many behavioral responses connected with the affective domain are experienced in science classes. For example, a student may express a love of biology due to the value attached to learning about animals, or a student may state that a theory of the origin of the universe conflicts with a personal religious belief. A student may experience a commitment to action in learning about the potential loss of an endangered species, while a study of the dangerous effects of radiation may cause a student to fear the use of radioactive isotopes in medicine. A need exists to understand the complex emotions associated with science topics and how they influence science learning.

Science educators have in the past called for research into the use of affect in improving science learning (Noddings 1996; Simpson, Koballa, Oliver, and Crawley 1995). The K-12 science curriculum focuses on the nature of science, including empiricism, predictability, experimentation, but a need exists for research into the emotions and feelings associated with studying science topics (Garritz 2010; Osborne et al. 2003; Simpson et al. 1995).

Krathwohl et al. (1964) have long suggested that there was no separation between the affective and cognitive domains of learning and that emphasis on one tended to drive out the other. Other researchers suggested that affective learning must be present for any cognitive learning to occur (Claxton 1991; Martin and Briggs 1986; Smith and Ragan 1999). Krathwohl et al. (1964), called for research into the types of classroom activities and interactions that would produce affective responses. Researchers suggested that a balanced approach to employment of instructional strategies to influence affect and cognition in education allowed for educational activities that addressed interest and value of a topic along with comprehension, application, and synthesis (Ringness 1975; Bloom et al. 1981; Simonson and Maushak 2001; Smith and Ragan 1999). Yet, as Quinlan (2016) noted:

> *Historically, one of the three taxonomies, now collectively called Bloom's taxonomies focused on educational objectives in the affective domain. However, the affective domain has had much less impact and application than the earlier taxonomy of the cognitive domain. The affective domain is deemphasized in the 2001 revision of the taxonomy.*
>
> (Quinlan 2016, p. 101)

Emotional scaffolding

There is, fortunately, a renewed call within the science education community to reconsider the potential impact on students' learning when emotional responses to science instruction are taken into account (Bellochi 2018; Bellochi et al. 2017; Quigley 2016; Richie et al. 2016; Zembylas 2016). The most pertinent of these contributions came from Quigley (2016), at least in relation to our current manuscript, because it speaks directly to the consideration of students' emotional responses vis-à-vis teaching practices when introducing the topic of climate change. Quigley noted, in a manner similar to that posed by Quinlan at the outset of this manuscript:

> *Positionality is a critical factor for teaching relationships; it sets the tone for learning, affecting its course and outcomes. It is absolutely essential for researchers working in environmental education to be aware of the complex ways in which the teacher's position shapes the power between teachers and students.*
>
> (Quigley 2016, p. 818)

Quigley, like Quinlan, recognized the powerful influence a teacher can have in determining whether students participate in or withdraw from discussions involving topics students perceive as being emotionally charged or potentially controversial—like climate change or evolution. With respect to evolution specifically, Scharmann (1990; 2005), Winslow et al. (2011), Oliviera et al. (2011), Nelson (1986), all noted that appropriate teacher positionality is necessary to encourage students to look for alternatives to a debilitating dichotomy rooted in emotional response—evolution or personal beliefs. But, management of students' emotional responses to evolution requires more than positionality and the building of positive student to teacher relationships. Zembylas (2013) strongly suggested that emotional management of students' perceptions demanded a relational analysis of the emotions themselves. It requires, therefore, an entire array of emotional scaffolding.

In a study of the affective domain and learning, for example, Rosiek (2003) examined the concept of emotional scaffolding as teachers used their knowledge and understanding of student emotions to encourage student learning. Data were collected from focus groups in the form of examples of pedagogical practices used by teachers to assist student learning. Focus group discussions were examined and cataloged by subject matter, intended effect, and scaffolding type. Focus groups reviewed other groups' discussions and contributed additional examples for designated categories. Findings indicated that emotional scaffolding was a frequent pedagogical practice designed to elicit and use students' emotional response to a topic. Data about this practice were organized into multiple case studies and narratives demonstrating examples of emotional scaffolding used to enhance learning. In one case, a teacher recognized that students were experiencing frustration and unease with a science activity requiring that they identify an unknown substance (Rosiek 2003). The teacher used the analogy of driving the lane in basketball to help the students move beyond frustration. In the example, a player didn't know which way the opponent would go, so he made a move to try to get the opponent to move in one direction. Similarly, in a science lab, the student must try one test to see which direction to go in the study progression. In this example, the teacher used knowledge of students' values of one topic and transferred that value to the classroom topic. The teacher created a bridge from a frustration response to a valuing response (consistent with Shulman's PCK concept).

Scharmann, Smith, James, and Jensen (2005) used reflection in lessons on evolution and the nature of science. These reflection assignments created emotional scaffolding for students during the study of evolution. Many of the secondary science teacher candidates in the study described themselves as Christian, or more often still, conservative Christian. Some students, who viewed it as a challenge to their faith, resisted the study of evolution. Scharmann et al. suggested that allowing students to place evolution and intelligent design along a continuum from less scientific to more scientific was less confrontational than asking them to accept or reject either topic. The activity provided emotional scaffolding by encouraging students with negative attitudes toward the theory of evolution to move beyond rejection of the topic to an understanding of the value of the theory. The researchers in the study created a classroom environment of respect for religious beliefs and values while encouraging study and discussion of the theory of evolution. The activity allowed students to find a new "place to stand" rather than requiring that they completely accept or reject evolution (Scharmann et al. 2005, p. 38). They concluded that a classroom environment of respect for religious beliefs and a thorough understanding of the nature of science facilitated successful understanding and valuing of the theory of evolution.

Emotional scaffolding, therefore, is crucial to the successful teaching and learning of evolution. Quinlan, once again, refers to four key relationships (Quinlan 2016), students with teachers being merely one of the four key relationships comprising a comprehensive emotional scaffolding—the others being students with subject matter, students with other students, and students with their developing selves.

Methods

Purpose of the study

Our purpose here is to examine the types of student emotional responses that secondary science teachers reported as emerging in their science classes and categorize students' behavioral responses as being representative of the four key relationships, identified by Quinlan (2016), as necessary for promoting both enhanced learning and individual student growth. After examining teachers' reports for science instruction more generally, the topic of evolution will be examined more closely. The research questions guiding the current study were:

Research questions

1. What types of student emotional responses do science teachers report are present in the classroom, as representative examples of Quinlan's four key relationships?
2. How do science teachers work with students' emotional responses in creating and maintaining a positive classroom learning environment?
3. How does the classroom environment change when instruction involves perceived controversial topics such as evolution, climate change, etc.?

Role of the researchers

We believe attention to cognitive development in education has come at the expense of development of ability and expertise in reaching the affective dimensions of student development. In our experience, creating opportunities for emotional response in the study of science contributes and magnifies student interest. During the duration of this study, we sought to consider and reflect upon these assumptions and biases throughout to allow open and honest responses from teachers and to communicate accurate results. While we acknowledge a strong connection with the teachers' positions as science teachers, we readily recognize that teachers have unique experiences that are valuable contributions for this study. We acknowledge that interpretation, while influenced by our backgrounds, must reflect the teachers' viewpoints and contributions to the study.

Participants

Eight teachers (3 females; 5 males) participated in this study, ranging in teaching experience from 2 to 6 years. All eight teachers were graduates of the same university and had completed a two-semester sequence of pedagogical coursework—Science Methods for Secondary and Middle Schools and Laboratory Techniques in the Teaching of Science. In these two courses teachers, during their secondary science education curriculum, were taught to present science through multiple representations and holistic dimensions using aesthetic, futuristic, historical, philosophical, and technological dimensions to complement traditional empirical views of science. Science topics considered by some preservice teachers to be controversial, such as theories of evolution, geological time, and the origin of the universe, were presented in the context of the nature of science, science as a way of knowing, and theories as powerful tools that permit us to explain, predict, and solve complex scientific problems and puzzles (Scharmann 2018; Scharmann et al. 2005). Open conversations on student concerns about the origin of life and the universe along with personal and religious values were encouraged. While the need for understanding the attitudes and interests of students in a high school science classroom was addressed in the science methods and laboratory techniques classes, formal study of the affective domain was not a part of the curriculum. The participants are referred to hereafter as teachers and identified by pseudonyms (Table 1).

Table 1 Teacher participants

Pseudonym	Gender	Content area
David	M	Biology
Ellen	F	Physics Earth Science
Eric	M	Biology
Greg	M	Biology
Jane	F	Physics
Jeff	M	Chemistry Earth Science
Louis	M	Biology
Sarah	F	Biology

Data collection

Semi-structured interviews with each of the eight teachers were conducted. The interview questions asked about activities and lessons occurring in participants' classrooms and the student behavioral responses that teachers had observed. The questions were designed to prompt teachers to describe emotional responses they had observed from their students (see Additional file 1). Prior to the study, three professional teachers not participating in the study reviewed the questions. Using their comments and suggestions, the interview questions were revised for the study. The intent of the interview was to hear teachers' experiences about emotional responses that they observed in their students during science lessons and that were in harmony with Quinlan's four key relationships. Teachers were encouraged with prompts and follow up questions to provide detailed descriptions about their experiences in working with student emotional responses. We added notes to the record of the interview, including demographic and teaching assignment information about the teachers. Following the interview, we added observations and insights to the interview record. Teachers were invited to review their interview transcript and make clarifications or corrections.

We also observed teachers' classes to add to the knowledge and develop an understanding of the lessons and activities that the teachers used and referenced in the interviews. Classroom observations allowed us to observe teachers and students in their natural setting and develop a greater understanding of their reports of student emotional responses (Creswell 2013a, b). We scheduled observations for two or more class periods of each teacher's classes and returned for additional observations in three of the teachers' classes to observe more activities. For observations, we recorded field notes containing the date and time, place, participant, content area, and notes about the activities and behaviors observed (Creswell 2013b; Merriam 1998). We described activities, discussions and conversations along with behavioral responses of students throughout the observations (Merriam 1998). Following observations, we conducted a debriefing with the teachers, discussing what had occurred and asking for clarification. To support the interviews and observations in the study, we obtained student work and instructional activity samples provided by the teachers (Creswell 2013b; Stake 1995). These teaching and learning artifacts were used only for triangulation with data collected in the form of interviews, observations, and notes.

Data Analysis

We used a constant comparative method (Ary et al. 2006) in the interpretation of the interview responses obtained from each of the eight teachers. Teacher interview responses were compared with field notes, direct observations of teacher instruction, and student work products from class periods observed to focus attention on teacher reports of students' emotional responses and the building of the relationships to make effective use of student emotion. All teacher interviews took place within 2 days of our direct observations. A complete delineation regarding how we parsed teacher interviews to create a set of statements that were categorized according to Quinlan's four key relationships can be found in Grauer (2014).

Teacher interview responses inconsistent with our direct observations, field notes, etc., prompted requests for additional clarification. Since we were using Quinlan's key relationships as a priori themes, they served as a template for the analysis (King and Horrocks 2010). If clarification did not yield a satisfactory resolution of the difference for the instance in question, that specific teacher's response was not included in the aggregate of interview responses; however, in the few instances where clarification was necessary, the differences were a matter of nuance. Once additional context was provided [e.g., reminding a teacher of the kinds of observations we were looking for; directly referring a teacher to reexamine their responses made in the selection questionnaire (see Additional file 1)], the accord between data sources was accomplished and the teacher response (originally in question), was added to the aggregated responses.

A random sample of 17 (~ 10%) of the teacher interview responses was obtained upon which to establish intercoder reliability in matching teacher interview responses as appropriately representing one or more of Quinlan's key relationships. One of the authors (a veteran science teacher educator with 35 years of experience modeling and mentoring the building of Teacher–Student relationships—see "Epilogue" section for a full discourse of this experiential base) provided Quinlan's original paper to a neutral party—an advanced doctoral student with a minor in mixed methods research and whose dissertation focused on Teacher–Student relationships. After a discussion of the paper and of the nature of the teacher interview responses as potentially representing none, one, two, three, or possibly even all four of the key relationships, the neutral party categorized each of the random sample teacher responses independently from one of the authors (who also coded the same random sample responses). For each of the individual teacher responses that was matched to a single relationship category (4 instances), the agreement was 100%. In instances where there were two relationships identified (9 instances) the agreement was also 100%. In those instances where a teacher response could be categorized as representing up to three relationships (4 instances), the agreement was 50%—however, in the two instances where there was a difference, both raters agreed on at least two of the categories. In summary, the two raters were completely consistent in categorizing fifteen of the seventeen interview responses (88%). The remaining teacher interview statements, representing descriptions of students' emotional responses to science instruction, were then coded by the author who had participated in the interrater exercise.

Results and discussion

A total of 168 instances of student emotional response were described by the eight teachers within their interviews. The 168 instances were obtained after we parsed each interview into a set of statements that most closely matched key phrases for each of the four key relationships identified by Quinlan (2016). Individual teacher interview responses retained for analysis contained at minimum one delineation of a key relationship; however, in many instances, a specific response represented two or even three of the key relationships. None of the teacher interview responses represented all four of the key relationships.

Research question 1

Data collected to answer research question 1—What types of student emotional responses do science teachers report are present in the classroom, as representative examples of Quinlan's four key relationships?—are reported in Table 2.

All eight teachers described at least one student response for each of the four key relationships, ranging from a minimum of 1 for Eric (student–student), Jane (Student–Self), and Louis (student–student) to a maximum of 13 for Louis (Subject–Student). The average profile across all eight teachers was 42% (Subject–Student), 29% (student–student), 39% (Teacher–Student), and 29% (Student–Self).

Research question 2

Once we identified the types of emotional responses teachers reported, we next examined research question 2—How do science teachers work with students'

Table 2 Teacher reports of students' emotional responses (as representing Quinlan's four key relationships)

Teacher	Frequency of relationship delineated (percent)			
	Subject–student	Student–student	Teacher–student	Student–self
David	12 (46%)	4 (15%)	5 (19%)	5 (19%)
Ellen	12 (52%)	2 (8%)	4 (17%)	5 (22%)
Eric	2 (25%)	1 (13%)	3 (37%)	2 (25%)
Greg	4 (25%)	6 (37%)	4 (25%)	2 (13%)
Jane	6 (50%)	3 (25%)	2 (17%)	1 (8%)
Jeff	11 (37%)	8 (26%)	8 (26%)	3 (10%)
Louis	13 (44%)	1 (3%)	8 (28%)	7 (24%)
Sarah	11 (46%)	4 (17%)	5 (21%)	4 (17%)
Totals (average Profile)	71 (42%)	29 (17%)	39 (23%)	29 (17%)

Table 3 Statistical analysis of teacher reports of students' emotional responses

Teacher	Relationship delineated (contribution to aggregate Chi square value)				Aggregate Chi square (df = 3)
	Subject–Student	Student–Student	Teacher–Student	Student–Self	
David	0.38	0.24	0.69	0.24	1.55
Ellen	2.38	4.76	1.56	1.47	10.18*
Eric[a]					
Greg	6.88	5.88	0.17	0.94	13.87**
Jane	1.52	3.76	1.56	4.76	11.62**
Jeff	0.60	4.76	0.39	2.88	8.63*
Louis	0.10	11.53	1.09	2.88	15.59**
Sarah	0.38	0.00	0.17	0.00	0.55
Average relationships profile	42%	17%	23%	17%	

* $p < 0.05$; **$p < 0.1$

[a] Eric contributed only 8 of the 171 data observations (< 5%) and was not included in the overall analysis

emotional responses in creating and maintaining a positive classroom learning environment?—to establish how teachers used students' emotional responses to construct key relationships. The construction of key relationships is of critical importance because in doing so, teachers create the emotional scaffolding discussed earlier in order to avoid unnecessary student resistance and withdrawal from subsequent introduction of evolution as a topic of study.

We compared individual teacher relationship profiles against the average profile by using a Chi square test (the average profile percentages serving as the expected values). The results of the Chi square tests are given in Table 3.

The profile for Eric was discounted for this analysis since he contributed only 8 total statements (< 5% of the total number of teacher statements) that matched with one or more of the Quinlan relationships. In addition, the profiles for David and Sarah were not statistically significant. The profiles for the remaining five teachers, however, were each statistically significant (as illustrated in Table 3). There existed a trade-off in the types of relationships emphasized (or de-emphasized), for each of these five teachers, as represented by the differing contribution of observed versus expected values obtained for individual relationships contributing to the aggregate Chi square value. In the cases of Ellen and Louis, for example, they exhibited a far lower than expected student–student relationship development compared to the average relationships profile. Ellen's profile, however, exhibits a greater than expected Subject–Student relationship, while Louis exhibits a greater than expected Student–Self relationship development.

Examples of teacher descriptions of student responses by relationship are given below concerning how science teachers work with students' emotional responses in creating and maintaining positive classroom learning environments.

Subject–Student relationships

> *Creating curricula and using teaching methods that involve students in inquiry are both intellectually and emotionally sound pedagogy. Such approaches help students build relationships with the subject, and between the subject and real-world questions, concerns, and problems.*
>
> (Quinlan 2016, p. 103)

Louis described behavior suggesting emerging student interest. He noted that his students began to show behavior indicating a developing interest. Louis described his students during their initial research about an environmental issue:

> *The first half [of the unit of study] was just research, I had articles for them to read. In the beginning that's what they did. We just read about that issue … And I kept stressing to the kids that these are good articles. I picked a variety of resources. They did balk at it at first and it was a bit of a struggle. But they started to get into it more as they went along. (Louis)*

Similarly, Sarah described her observations of students becoming more interested and showing a willingness to work on assigned activities without pressure. She observed that over time the students began to work on assignments quickly, and their 'noisy' voices indicated they were responding with positive emotions to the activity:

> *At the beginning of the semester when I give a project, it's kind of slow going. As we go through the semester, they dig into it faster. I will see them immediately bring the computers out and go and start work as opposed to taking their time, messing around. And this is really general because I have classes where kids won't do that. [In this statement, Sarah commented on the class as a whole but pointed out that there were some individual students who did not behave this way.] But in general as the semester goes on, they'll dive more and more into what's going on. And that will be my measure of what kind of interest they are developing, how much they care about the topic and how they feel about their ability to do the assignment. When I've got them with me [when they are active and interested in the assignment] it gets to be noisy because I encourage them to talk to each other, to share with each other. (Sarah)*

In this example Sarah used the phrase "when I've got them with me" to indicate that she believed her students were developing an interest in the topic. She believed that when students developed interest, they showed their enthusiasm by getting to work on the assignment quickly without prompting and by becoming noisy and talkative [Note: this is also an example of encouraging student–student relationship development].

Ellen indicated that she believed that when her students made a connection between their science lessons and applications outside the classroom, it showed that they valued the topic because they could see how it applied to their lives. Ellen commented further on her students valuing physics as they dispelled misconceptions about inertia and recognized everyday applications:

> *It was something they could see in their everyday lives. Or they could apply it to something they did. So you would see them move from just talking about it like it was a cool thing to know to, 'Since I know this happens here, then I know that this will probably happen in this other thing.' It's like once they were able to let go of the misconception, then they started connecting everything in a logical way and it was more important to them that they could. I think they were really seeing the value of physics and how they could move from one concept to another. (Ellen)*

Ellen believed that students talking about complex connections between physics concepts demonstrated that they valued the topic. Her statement about student comments changing from "talking about it like it was a cool thing to know" to explaining a physics concept described behavior that she believed represented valuing.

Finally, in an example that involved students in authentic inquiry, David believed that his students demonstrated that they valued ecology when they developed a deeper understanding and showed advanced interest in ecological relationships. His students created water ecosystems in gallon jars using fish, algae, and other materials. In the following passage, David related how his students formed an understanding of the interconnection of organisms through the ecosystem activity. His students showed consistent commitment as they continued to collect data on their ecosystems beyond the time of study:

> *I have students come in every day so interested to see if theirs [ecosystems] are still going. They have taken huge ownership of that. They can tell you everything as to why their ecosystem is still alive and why some have died. We're starting to see some cycling going on a little bit; everything from mold to algae. On a sunny day like this we will see bubbles being developed as oxygen is produced by the algae. That is their interest. We are not even studying it anymore but that is the first thing they do every day is check on the ecosystems that are still alive. (David)*

In this quotation, David described his students showing advanced interest in the topic, a valuing behavior.

Further, as David's students continued to work on additional ecology activities and developed an understanding of how organisms, including humans, "start working together" they developed appreciation of the topic and expressed an interest in the field:

> *You know most kids don't like photosynthesis and respiration because it's so complex. But they started realizing about how we start working together and things outside work together [ecological relationships in an ecosystem]. We started to do some things outside [activities which were extensions of the ecosystem project] so of course the kids all of the sudden want to be an ecologist. 'I want to work outside. I want to work with these things.'* *(David)*

In the previous passage, David explained that he believed his students had moved beyond showing a willingness to learn about the topic to valuing the topic of photosynthesis because of their demonstrated understanding of the complex connections in the ecosystem. He also noted that they showed that they considered the topic to have worth by expressing an interest in the field of ecology.

Student–Student relationships

> *As educators, we can create environments that help students to build these important peer relationships. We can do so through [classroom] environments that offer opportunities for students to discuss what they are learning informally … by dividing students into smaller groups and giving them meaningful tasks that require them to share their knowledge and learn from each other.*
>
> (Quinlan 2016, p. 106)

Several teachers suggested that collaborative groups provided their students with opportunities to form relationships with their classmates and that in doing so, created a much more positive classroom learning environment for a variety of reasons. Greg, for example, described his students supporting each other in collaborative groups:

> *They would push each other. They worked in teams and they really like to push each other. They would get into their little groups and they would flat just start on their research papers. They motivated each other. Some of the groups just pushed each other pretty hard.* *(Greg)*

Jeff also reported using collaboration to help his students to move from receiving information into responding with positive emotions:

> *I took a hard look at how they were working, what their grades were....I was doing a lot of lecturing, and I started putting it more on them. I required that they work together in groups. They have to answer questions together on their own without my lecture. In the collaboration they enjoy what they are doing. When they get to the point, every once in a while, they look at something and realize that they really have got a grip on it and realize they understand it, they will get that satisfaction, that response then.* *(Jeff)*

Jeff further explained that he had to create an effective lesson activity in order for his students to collaborate successfully:

> *One of the changes is that they have to use these specific terms to describe [or] explain what's going on, trying to get them to incorporate a real specific vocabulary to describe what happened rather than relying on the shortest answer they can come up with. So I have them use these terms for the description. That's fairly new. They work on their explanation in their small groups and hang onto it for our large group discussion. So before they turn it into me, we can go over it. We discuss it in the large group, so the large group pushes the small groups and encourages those who aren't sure of their descriptions and helps them get the material. Then once they have that large group discussion (Teacher–Student relationship), they are more confident in their answers.* *(Jeff)*

When asked how he knew that they had developed confidence, Jeff responded:

> *They aren't just sitting around. They talk to each other. They look happy and they sound happy. Now that they [are] getting more used to working together, I see them starting to get past just trying to get the answer and looking at understanding what is really going on in chemistry. They will talk about what is happening in a chemical reaction—what the changes are and how they happen. They get to talking together, working together, and you can see the expression in their faces that they know they can do this.* *(Jeff)*

In this description, Jeff explained that he had to encourage his students to work with each other. He also described his methods in using collaborative groups to help students develop better answers. As a result of effective collaboration, his students showed emotional behavior indicating enjoyment.

David also described students demonstrating enjoyment during collaborative activities. When asked about the types of emotions he observed when his students worked in groups, David responded:

> *Enjoyment—they come to life, their faces, the way they talk to each other and laugh. It was fun to see groups that don't normally work with each other, and then they get into it. They get into a whole different activity [in groups] than what they would normally be doing [individually] and they get along. They are enjoying what they are doing, and they build a connection with each other that they wouldn't have without the group activity. I would say every group—I give them a chance to write a reflection at the end of every project and I didn't have one say that they didn't like working in their group.* *(David)*

[Note—Quinlan specifically remarks that it is of paramount importance to, "Design learning activities that also have a component of fun. Sharing laughter builds relationships." (p. 106)].

Teacher–Student relationships

> *Relationships between students and teachers are important in creating classroom atmospheres of trust and cooperation. Opening ourselves up to students requires us to be aware of our own emotions, to observe and interpret students' emotions, and to cope with students' feelings as they are expressed. All of these are demanding and important – if rarely acknowledged – aspects of teaching.*
> (Quinlan 2016, p. 105)

Sarah believed that interacting through conversation allowed her to reassure the students that she was interested in their ideas. She indicated that conversation was a safe venue for her students to talk about their ideas and understanding of science. Sarah described using conversation to build student trust and confidence in their abilities:

> *I will throw questions out, and we will just start exchanging ideas. Or when I want to see how much they know, I will put up questions, and we will end up talking about some things. I can't do that early on because most of the students won't open up, because they know they can't do science. So, they are not going to contribute because, 'What if someone laughs at them? What if it's a stupid idea?'... So, I have to build through the course of the semester to get to that point. I've got to build that trust with them that they can bring their ideas, and it will be part of a conversation and not something that they will get picked on later.* *(Sarah)*

In the previous account, Sarah explained that some of her students did not have confidence in their abilities in science. She suggested that they hesitated to speak up or share ideas in the classroom for fear that the other students might make fun of them later on.

Teachers also used conversation to build student comfort levels and encourage interaction as negative affect surfaced in the study of controversial topics such as evolution and geological time. Louis described talking to students to improve their comfort levels in the study of geological time:

> *After the first day or so, they start to realize I'm not challenging their beliefs. We talk about it and they get comfortable with that. I let them talk about what they believe if they want to. They realize I'm not trying to change them. After that they don't seem to mind listening to the evidence.* *(Louis)*

Finally, teachers also used students' emotional responses as an indicator of student interest. Ellen commented on using student response and interest to let her know that students were learning:

> *One of the things that I hate as a classroom teacher is the feeling that I am talking at them and don't have any feedback. I've got to have feedback. I've got to have response, I have to have interaction, and I would rather have a classroom that is verging on out-of-control, that people are talking and communicating, than one that is incredibly quiet and well behaved. Because if they are well behaved, they are probably not thinking, not interested.* *(Ellen)*

In this statement, Ellen shared that she used student interest and response as feedback. She described the need for interaction between students, suggesting that it indicated both interest and thinking.

Students-Self relationships

> *The focus on critical thinking ... prompts students to question received wisdom, including value positions taught by their families or practiced in their home communities ... Thus, students must not only deconstruct old meanings and ways of making meaning but reconstruct a sense of purpose in their own life that integrates expanded perspectives and worldviews.*
> (Quinlan 2016, p. 106)

A relationship between students and their developing selves manifests itself, according to Quinlan, in whether we ask students real questions, engage them in deep reflection, allow them to test their limits, and/or create an environment of trust within which a dialog between teachers and students permits freedom for students to express honest feelings about the subject matter. In this study, while we noted 29 instances of students' emotional responses that matched this category, the instances were not universally positive. For example, among the biology and earth science teachers interviewed for this study, we noted several negative expressions of student emotion.

Jeff reported, for example, that his students expressed their religious beliefs during the study of geological time. He noticed his students revealed conflict between their religious beliefs and science theories:

> *I'm not certain that they are real comfortable with that [comparing science and religion]. Their body language, them looking at each other, a little hesitant to address it, there is a struggle going on. But I don't see them willing to resolve it. We did a little bit of that [comparing science topics with religious beliefs], but they did not change their positions. (Jeff)*

In this description, Jeff believed that his students were reflecting on their own internal value systems but were not willing to compare those values with science topics.

By contrast, Louis was not dissuaded by initial student resistance to the topic of evolution. In fact, he seemed to have anticipated and was prepared to deal with the resistance in a positive way:

> *Their arms go from this to more open [showing crossed arms to open arms] when we talk about human evolution and how it is a big misconception that monkeys evolved into humans. They think that a chimp stood upright and was a human the next day. That is a lot of their view of evolution. When I dispel that misconception, then they are much more open in body language. Those that are resistant at first, when they see that what they have been taught about chimps evolving into humans isn't accurate, then they are much more open to learn about it. (Louis)*

In this statement, Louis indicated that he watched for student body language to indicate student attitude toward the topic of evolution. He observed changes in body language as students learned accurate information about evolutionary theory.

Research question 3

The section above, which considers the development of students with their developing selves, was directly related to Research Question 3—How does the classroom environment change when instruction involves perceived controversial topics such as evolution, climate change, etc.?—and it is this relationship we now explore independently.

David, like Louis, indicated that student body language showed that changes in attitude occurred as he provided accurate information on evolution.

In addition to being alert to student body language, teachers indicated that they managed students' concerns about religious beliefs in the study of controversial topics by calmly talking about the science of the topics. David noted that talking to students about the science of evolution helped students overcome their concerns:

> *We just talk about it. You know evolution is a natural process and we're just going to learn about it. We're not going to bring up God and all that. We are going to talk about what naturally happened and look at the known facts.... They always worry. I tell them we don't know what really happened. None of us were here. That usually helps them be more willing to look at it. (David)*

In this statement, David explained that talking to students about science as a way of explaining natural processes aided students in becoming more open to learning about evolution.

Louis explained that he encouraged students to compare their beliefs with their understanding of evolution:

> *We start the unit off with a discussion of their understanding of evolution. They write any explanations of the origin of the species that they are aware of. The next day, we talk about it. We make a list of reasons for learning and reasons against learning about evolution. Of course, religion comes up. I show a web site that has ten creation stories from different cultures. I share a few of them with the class. The students are surprised. We will talk about how religion influences their beliefs on evolution. We talk about how in science class we will learn about the science explanation about how things came to be. (Louis)*

Jeff also talked to students and addressed their concerns about conflicts between their religious beliefs and science. He explained the need to develop an accurate understanding of science and the value of science for making predictions:

> *I just talk to them, 'This is what the science says, and this is what I want you to understand. And what you do with it is up to you. I don't require that you believe in it, but you do need to at least understand it.' And I try to get across that science is valued for making predictions in our lives, improving our lives… and I will leave it there. (Jeff)*

Similarly, Ellen addressed the conflict by discussing how science and religion provided answers in different areas:

> *We have had discussions about religion and theology.... One of the things we ended up talking about was that religion and science answered different questions. And if you look back in history, any time that it seems like there has been a major disagreement between science and religion, if you wait a couple of hundred years, it gets resolved.* (Ellen)

Eric worked to help his students get past their concerns about conflicts with their religious values. He explained that the information that his students learned about evolution could help them in future decisions:

> *I brought it up in a way that wouldn't make them think I was trying to preach to them, and I worded it very carefully, so they didn't think I was trying to give them values. I'm giving them information. I'm giving them facts. I worded it very carefully so I would have people thinking; I was not trying to put their religion in question. I was trying to convey information that they may find pertinent to a decision they might make in the future.* (Eric)

These preceding accounts by teachers indicated that development of an accurate understanding of the facts supporting evolution helped students become more comfortable with the topic. As noted by David, "I tell them to look at it in terms of the facts we know. A lot of it is just a theory. Most of them are open to that."

In the following passage, Louis described his experience with managing affect in students showing concern about the study of evolution. Louis illustrated the process of managing student affect by (a) being alert to student behavioral responses showing concern, (b) responding to student affective behavior by calmly talking about the science of evolution, and (c) providing accurate facts and information about evolution. Louis initially noted his students' behavior:

> *I could tell from the things they said or their body language or the facial expression that, 'This guy is going to make me learn about evolution. He's going to take my religion away from me.'* (Louis)

Louis calmly talked to his students about the science of evolution as a tool for understanding the natural world:

> *I talk about using tools from the tool belt. This is just another tool. I get out a container and I put in scissors and rulers and crayons and markers. I say, 'OK this is your knowledge.' I say, 'If we learn about evolution, I'm just putting more things into your knowledge bucket. I'm just putting things into your bucket.'* (Louis)

In the preceding statement, Louis described how he responded to students showing body language that indicated negative affect toward the topic of evolution by calmly talking to them about the use of the science of evolution as a tool for understanding and gaining knowledge. Following that, rather than challenging their religious beliefs, he provided facts and relevant information about evolution to allow students to maintain their belief system *and* consider evolution to be valuable knowledge:

> *What I do is right away hit them with applications. The second day of class we watch a video about HIV and doctors talking about how they wouldn't be able to treat patients with HIV if they didn't understand how viruses evolve.... I want them to see that regardless of what they believe that knowledge is what is important. I do a ton of applications with antibiotics at this point. We do case studies with antibiotic resistance.... I think evolution is one of those topics that it's hard to get past their beliefs. I think I'm good at teaching it. If they can tell you why they have to take antibiotics till they are gone, if they are going to be a doctor why it's important, or to a parent that has a sick child, then I have accomplished what I want them to learn.* (Louis)

Louis revealed that he believed that he had developed effective techniques for managing student affect associated with the study of evolutionary theory. He considered it necessary to address student beliefs. His goal was to help his students develop an understanding of the application of evolution to medical problems.

Sarah explained that use of the term evolution produced affective responses indicating students were concerned about the relationship of evolution to their beliefs. To manage student affect, she introduced evolution to her classes through natural selection:

> *The way I introduce evolution is I do everything natural selection. So, they don't actually hear the word evolution until the end of day two of my talking about natural selection, because by then they understand what it really is. If you start with 'Today were going to talk about evolution,' I've had kids who go, 'Well I don't believe in evolution.' But If I talk about natural selection and talk about how animals become more adapted to their situation, and then I introduce Darwin they say, 'Oh is that what it's about?' The buzzword [evolution or Darwin] can't be there initially, because that's all they are taught, that the buzzword is bad, not why. So, if I can go around*

> *that [avoid the use of Darwin's name initially] and explain first, then I can get around that.* (Sarah)

In the preceding passage, Sarah explained that she believed some students responded to terms such as evolution and Darwin in a negative way and that she needed to help them get past their concerns. She managed her students' negative responses to evolution by talking about processes such as natural selection that they could understand and then explained how those processes were a part of evolutionary theory. In this way, she avoided students' initial concerns about their beliefs and created knowledge that supported their ability to achieve organization level affect.

These accounts indicated that not only were these teachers able to use students' emotional responses appropriately, but that they were able to manage it in their classrooms. Their ability to respond to student emotional responses allowed them to assist students in overcoming their discomfort and learn about topics that they felt were in conflict with their religious values. Teachers' descriptions indicated that discussions and conversations were important in managing students' emotional responses.

Conclusions

With respect to evolution instruction, I have spent over 35 years recommending (and iteratively revising) appropriate positionality for novice teachers that permit them to reflect, reconcile their personal views, and engage their future students in more honest conversations about the power and limits of scientific theories. Taken *writ large*, the most salient recommendations, resulting from this study, to manage emotional responses to evolution instruction are to:

- Foster relationships that engage students in positive conversations.
- Construct relationships in an appropriate sequence—Teacher–Student and Subject–Student first, followed by student–student and finally nurturing students with developing selves.
- Use non-threatening assessments.
- Allow students to privately express their honest feelings about the science being learned.

Epilogue: Learning across a career to establish critical relationships

One of us has been engaged in preparing novice science teachers since 1985. Along this career journey, many changes have taken place in how I have modeled peer discussion as a means to foster both student–teacher and student–student relationships. In science teaching methods courses, for example, I adopted Schwab's suggestions discussed earlier in this paper and used evolution as the subject matter by which to engage students in modeling peer discussion as a pedagogical tool. This met with immediate disaster—one discussion group was being led by a non-traditional undergraduate who was extolling creation science as the superior alternative explanation for origin of species; another group was talking over one another in heated argument. Clearly, I had much to learn about my craft as a university professor!

My second through several subsequent attempts were much improved after several discussions with a key mentor, Craig E. Nelson, Emeritus Professor of Biology (Indiana University). Nelson implemented peer discussion as early as the mid-1970s and described the benefits of this pedagogy in promoting critical thinking (Nelson 1986, Nelson et al. 1998, Nelson 2008, 2010; Nelson et al. 2019). Crucial to the success of peer discussion pedagogy is relevant subject matter and the establishment of structured guidelines for how peers should interact—what is off-limits and what should be encouraged—to facilitate the building of positive student–student relationships. In addition, after bringing students back from peer discussion to a whole class debriefing, addressing relevant points of student uncertainties, misconceptions, and coming to consensus becomes critical (and also models the consensus building process used by scientists in the construction of new knowledge). A delineation of the benefits (and thorny issues I faced) in applying peer discussion pedagogy to evolution education can be found in Scharmann (1990; 1994a).

I gained further insight into how peer discussion was infrequently being employed by inservice science teachers through my conduct of a National Science Foundation (NSF) sponsored project—*Nature of Science and Premises of Evolutionary Theory* (NOSPET; 1989–1992). Teachers were generally reluctant to turn over control to students regarding a subject such as evolution. It was here that my exposure to William Perry's work (Perry 1970) in my doctoral studies with Nelson came to crucial fruition. I was now able to model how to make effective use of peer discussion for NOSPET participants, structuring how to initiate Subject–Student, student–student, and Teacher–Student relationships (Scharmann and Harris 1992; Scharmann 1994b). NOSPET teachers were able to move beyond the concern of control to a concern of collaboration—building strengthened relationships with their students prior to and during evolution instruction.

Still missing at this stage of my career, nonetheless, was an implementation of critical thinking pedagogy that would more directly foster the relationship of students with developing selves in a manner that would allow more of my graduates to feel comfortable in fostering this key relationship. The results of this current study are highly encouraging in that respect. All eight teachers were able to identify the development of each of the four key relationships identified by Quinlan as crucial for instructional success. However, only Louis, Ellen, and David, through their interview responses, emphasized the student-developing selves relationship in a manner commensurate with what was modeled for them in science teaching methods. Louis was especially effective here, yet even he did so at the expense of the student–student relationship (although Schwab would likely consider this a not unusual trade-off if this was consistent with Louis' self-assessment of his "needs of the teacher" to more effectively provide evolution instruction).

I thus turned my focus back to my preservice teacher candidates. This was of even greater importance in the State of Kansas at the time (late 1990s), since the election of a State Board of Education put the study of evolution in question for every individual school district in the state.[1] Collaboration with Mike U. Smith—friend, colleague, and co-author—provided opportunities to brainstorm and create seminal examples of using nature of science (NOS) as a focus of study explicitly taught prior to the introduction of evolution as a topic of study (Smith and Scharmann 1999, 2008; Scharmann and Smith 2001; Scharmann et al. 2005). Crucial to the successful critical thinking of undergraduate novice teacher candidates was explicit and reflective NOS and evolution assignments. The prominent tenets of which are delineated in Scharmann (2018) and Nelson et al. (2019).

Continual refinement of this explicit and reflective pedagogical approach has taken place since 2008. I worked with Wilbert Butler, Jr., for example, at Tallahassee Community College to explore NOS-rich evolution instruction employing reflective journals as a non-threatening assessment strategy, previously noted in this paper (Scharmann and Butler 2015). Finally, in working with a recent cohort of novice teachers, I created a month-long study of Stephen J. Gould's seminal *Rocks of Ages—Science and Religion in the Fullness of Life* (Gould 1999). The journaling described in Scharmann and Butler (2015) was modified to integrate in-class discussions that promoted on-going development of Teacher–Student, student–student, mutual trust, and access to student-subject relationship, all while affirming the power, value, yet limits of science 'as-a-way-of-knowing' and the status of religion as a complementary magisterium (Gould's term). This month-long assignment produced the most salient student with developing selves relationships I have been able to foster in a 35-year career focused on evolution education. All twenty members of this novice teacher cohort illustrated the paramount importance of reconciling one's feelings about science and religion prior to taking on the task of helping their future students to do the same. As illustrations of the depth of their reconciliation, take for example the following reflective essay excerpts:

> *I do want to take some space to sort my thoughts between science and religion. As a Christian, I fully believe in the Creation story and that God is above all and in all things, orchestrating it all with grace and absolute truth. Additionally, with the help of this class, I can see how science and religion can exist in the same thought - one does not have to win the debate. Science cannot prove or attempt to explain supernatural phenomena and I find peace in that. Due to my strong beliefs though, I hesitate to claim that Intelligent Design is not a science. In doing so, I feel like I am stripping it of validity. This is a silly thought though, because who would I be to be able to strip a Supreme Being of something that is their very nature? So, the past few weeks have been composed of myself processing how claiming things more scientific than my religious views is acceptable due to the [criteria] we have for science- in MORT [measurable, observable, repeatable, testable], NOMA (non-overlapping magisteria of science and religion), etc. Science and religion, for the sake of the tension between the two and the essence of what each area focuses on, should not overlap. Science does not study- cannot study- what Intelligent Design is. That is not a capability of science because it is beyond all human intuition and what we could dream up on our own. While I could argue that the mind of God is a scientific one- due to His design of a "fly's hind leg, the bacteria flagellum, blood clotting systems," I cannot support that argument in terms of the realm of science. [Student A]*

> *The use of a scientific continuum [one field of study being more scientific in comparison to another] is beneficial in communicating the nature of science because, as we've discussed in class, it eliminates the notion that a student must be absolute in making a choice between the entirely too simple phrases, "yes" and "no," and other equally dichotomous statements. It instead characterizes his or her learning environment as one in which it's okay to be in the gray area, to be skeptical, to be curiously unwilling to choose a single path right away. In accordance with the nature of science itself, there is hardly ever one "correct" way to explain a phenomenon or solve a problem, so why present such a position to*

[1] The concern over teaching evolution in Kansas was appropriately depicted in the book *What's the Matter with Kansas* (Frank 2007).

> *students? Using a continuum also helps prevent students from being embarrassed in front of his or her peers or teachers, unlike if they had to choose one side and one side only. ... In a more practical sense, sometimes the use of a continuum may be unattractive simply because the deeper discussions that can result from such a technique may take up more class time, which some teachers (and students) might rather use for other things. I feel it is important to note, however, that I am one who would prefer to evoke deeper, more meaningful discussions among my students rather than to only skim the surface in order to get more things done. I feel confident in my ability to be flexible and catch up if the need arises.* [Student B]

It is not without pitfalls across a career that we learn to establish the critical relationships delineated in this study. Establishing and implementing Quinlan's four key relationships leads to more efficacious pedagogies. In turn, adopting efficacious pedagogies to replace outmoded ones in science teacher education is an intentional choice and must be deftly modeled. If we do not adopt such pedagogies and model appropriately, we will continue to fail to meet the needs of science teacher candidates in how best to teach evolution (and related sensitive subject matters) to their future students (Borgerding and Dagistan 2018; Glaze et al. 2015; Hermann 2013; Rutledge and Warden 2000). To continue to serve our teacher candidates' future student populations poorly puts at risk the political decision-making (i.e., by informed voters) needed within a citizenry to make individual health and societal decisions based on accurate scientific reasoning.

Supplementary information

Supplementary information accompanies this paper at https://doi.org/10.1186/s12052-020-00128-6.

Additional file 1. Selection questionnaire.

Abbreviations

BSCS: Biological Sciences Curriculum Study; CRS: Cultural and Religious Sensitivity; MORT: Measurable, Observable, Repeatable, Testable; NOS: Nature of Science; PCK: Pedagogical Content Knowledge.

Acknowledgements

The authors would like to first extend their sincere thanks to Zach Schafer and John Moeller for their timely assistance in reading various iterations, intellectually questioning various sections, and making constructive suggestions that have greatly improved the logical flow and technical accuracy of the manuscript. Zach and John are, in addition, both gifted educators who recognize and establish the key relationships described throughout this manuscript. Second, we are grateful for the ongoing personal involvement by Craig E. Nelson (Emeritus Professor of Biology, Indiana University) in discussing the concept for and ultimate synthesis of this current manuscript. Finally, we would like to thank the eight teachers who participated in this study. The eight teachers represent a cross-section of early career graduates from the Kansas State University College of Education science teacher education program who were eager to participate and provide insights into building appropriate relationships with their respective students.

Authors' contributions

This paper was co-authored by LCS and BG. Both authors read and approved the final manuscript.

Funding

Not applicable.

Availability of data and materials

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1] Teaching, Learning, and Teacher Education, University of Nebraska-Lincoln, Lincoln, USA. [2] Carl R. Ice College of Engineering, Kansas State University, Manhattan, USA.

Received: 4 April 2020 Accepted: 28 May 2020
Published online: 05 June 2020

References

Alsop S, Watts M. Science education and affect. Int J Sci Educ. 2003;25:1043–7.

Ary D, Jacobs LC, Razavieh A, Sorensen C. Introduction to research in education. 7th ed. Belmont: Thompson-Wadsworth; 2006.

Bellochi A. Early career science teacher experiences of social bonds and emotion management. J Res Sci Teach. 2018;56:322–47.

Bellochi A, Quiqley C, Otrel-Cass K. Exploring emotions, aesthetics and wellbeing in science education research. Switzerland: Springer International Publishing; 2017.

Bertka CM, Pobiner B, Beardsley P, Watson WA. Acknowledging students' concerns about evolution: a proactive strategy. Evolution. 2019;12:3. https://doi.org/10.1186/s12052-019-0095-0.

Bloom BS, Madaus GF, Hastings JT. Evaluation to improve learning. New York: McGraw-Hill; 1981.

Borgerding LA, Dagistan M. Pre-service science teachers' concerns for teaching socioscientific and controversial issues. J Sci Teacher Educ. 2018;29:283–306.

Bybee RW, Taylor JA, Gardner A, Van Scotter P, Powell JC, Westbrook A et al. The BSCS 5E instructional model: Origins, effectiveness and applications, Executive summary. Colorado Springs: Biological Sciences Curriculum Study; 2006. https://bscs.org/resources/reports/the-bscs-5e-instructional-model-origins-and-effectiveness. Accessed 24 March 2020.

Claxton G. Educating the inquiring mind: the challenge for school science. New York: Harvester Wheatsheaf; 1991.

Creswell JW. Research design: qualitative, quantitative, and mixed methods approaches. Thousand Oaks: Sage; 2013a.

Creswell JW. Qualitative inquiry and research design: choosing among five traditions. 2nd ed. Thousand Oaks: Sage; 2013b.

Frank T. What's the matter with Kansas?. New York: Henry Holt and Company; 2007.

Garritz A. Pedagogical content knowledge and the affective domain. Int J Scholarship Teach Learn. 2010;5(2):1–6.

Glaze AL, Goldston MJ, Dantzler J. Evolution in the southeastern USA: factors influencing acceptance and rejection in pre-service science teachers. Int J Sci Math Educ. 2015;13:1189–209.

Gould SJ. Rocks of ages: science and religion in the fullness of life. New York: The Ballantine Publishing Group; 1999.

Grauer BL. Secondary science teachers' use of the affective domain in science education. 2014. https://krex.k-state.edu/dspace/handle/2097/17312. Accessed 29 Apr 2020.

Hermann R. High school teachers' views on teaching evolution: implications for science teacher educators. J Sci Teacher Educ. 2013;24:597–616.

Holt EA, Ogden H, Durham SL. The positive effect of role models in evolution instruction. Evolution. 2019;11:11. https://doi.org/10.1186/s12052-018-0086-6.

James MC, Scharmann LC. Using analogies to improve the teaching performance of preservice teachers. J Res Sci Teach. 2007;44:565–85.
Kampourakis K. Understanding Evolution. London: Cambridge University Press; 2014.
King N, Horrocks C. Interviews in Qualitative Research. Los Angeles: Sage Publications; 2010.
Klopfer LE. A structure for the affective domain in relation to science education. Science Education, 1976.
Krathwohl DR, Bloom BS, Masia BB. Taxonomy of educational objectives: Handbook 2: affective domain. Longman. 1964;60:299–312.
Martin BL, Briggs LJ. The cognitive and affective domains: integration for instruction and research. Englewood Cliffs: Educational Technology Publications; 1986.
Merriam SB. Qualitative research and case study applications in education. San Francisco: Jossey-Bass; 1998.
Nelson CE. Teaching evolution (and all of biology) more effectively: strategies for engagement, critical reasoning, and confronting misconceptions. Integr Comp Biol. 2008;48:213–25.
Nelson CE. Creation, evolution, or both? A multiple model approach. In: Hanson RW, editor. Science and creation: geological, theological, and educational perspectives. New York: Macmillan; 1986. p. 128–59.
Nelson CE, Nickels MK, Beard J. The nature of science as a foundation for teaching science: evolution as a case study. In: McComas WF, editor. The nature of science in science education. Norwell: Kluwer Academic; 1998. p. 315–28.
Nelson CE, Scharmann LC, Beard J, Flammer LI. The nature of science as a foundation for fostering a better understanding of evolution. Evolution. 2019;12:6. https://doi.org/10.1186/s12052-019-0100-7.
Nelson CE. Want brighter, harder working students? Change pedagogies! Some examples, mainly from biology. In Millis BJ, ed. Cooperative learning in higher education. 2010. https://digitalcommons.georgiasouthern.edu/ct2-library/87. Accessed 24 Mar 2020.
Noddings N. Stories and affect in teacher education. Camb J Educ. 1996;26:435–647.
Oliviera AW, Cook K, Buck GA. Framing evolution discussion intellectually. J Res Sci Teach. 2011;48:257–80.
Osborne J, Simon S, Collins S. Attitudes towards science: a review of the literature and its implications. Int J Sci Educ. 2003;25:1049–80.
Perry W. Forms of intellectual and ethical development in the college years. New York: Holt, Rinehart, and Winston; 1970.
Pobiner B, Beardsley PM, Bertka C, Watson WA. Using human case studies to teach evolution in high school A.P. biology classrooms. Evolution. 2018;11:3. https://doi.org/10.1186/s12052-018-0077-7.
Quigley C. Emotions in teaching environmental science. Cult Sci Edu. 2016;11:817–22.
Quinlan K. How emotion matters in four key relationships in teaching and learning in higher education. College Teaching. 2016;64:101–11.
Quinlan. 2020. About. *Linkedin*. https://uk.linkedin.com/in/kathleen-m-quinlan-12a0111b. Accessed 25 Mar 2020.
Richie SM, Hudson P, Bellochi A, Henderson S, King D, Tobin K. Evolution of self-reporting methods for identifying discrete emotions in science classrooms. Cult Sci Educ. 2016;11:577–93.
Ringness TA. The affective domain in education. Boston: Little, Brown and Company; 1975.
Rosiek J. Emotional scaffolding: an exploration of the teacher knowledge at the intersection of student emotion and the subject matter. J Teacher Educ. 2003;54(5):399–412.
Rutledge ML, Warden MA. Evolutionary theory, the nature of science, and high school biology teachers: critical relationships. Am Biol Teacher. 2000;62:23–31.
Scharmann LC. Enhancing an understanding of the premises of evolutionary theory: the influence of a diversified instructional strategy. School Sci Math. 1990;90:91–100.
Scharmann LC. Teaching evolution: designing successful instruction. J Sci Teacher Educ. 1994a;5:122–9.
Scharmann LC. Teaching evolution: the influence of peer teachers' instructional modeling. J Sci Teacher Educ. 1994b;5:66–76.
Scharmann LC. A proactive strategy for teaching evolution. Am Biol Teach. 2005;67:12–6.
Scharmann LC. Evolution and nature of science instruction. Evolution. 2018;11:14. https://doi.org/10.1186/s12052-018-0088-4.
Scharmann LC, Butler W. The use of journaling to assess student learning and acceptance of evolutionary science. J Coll Sci Teach. 2015;45(1):11–6.
Scharmann LC, Harris WM. Teaching evolution: understanding and applying the nature of science. J Res Sci Teach. 1992;29:375–88.
Scharmann LC, Smith MU. Further thoughts on defining versus describing the nature of science. Sci Educ. 2001;85:691–3.
Scharmann LC, Smith MU, James MC, Jensen M. Explicit reflective nature of science instruction: evolution, intelligent design, and umbrellaology. J Sci Teacher Educ. 2005;16:27–41.
Schwab JJ. The practical 3: translation into curriculum. School Rev. 1973;81:501–22.
Shulman L. Those who understand: knowledge growth in teaching. Educ Res. 1986;15(2):4–14.
Simonson M, Maushak N. Instructional technology and attitude change. In: Jonassen D, editor. Handbook of research for educational communications and technology. Mahway: Lawrence Erlbaum Associates; 2001. p. 984–1016.
Simpson R, Koballa T, Oliver J, Crawley F. Research on the affective dimensions of science learning. In: Gabel D, editor. Handbook of research on science teaching and learning. New York: Macmillan; 1995. p. 211–50.
Smith P, Ragan TJ. s. New York: Wiley; 1999.
Smith MU, Scharmann LC. Defining versus describing the nature of science: a pragmatic analysis for classroom teachers and science educators. Sci Educ. 1999;83:493–509.
Smith MU, Scharmann LC. A multi-year program developing an explicit reflective pedagogy for teaching pre-service teachers the nature of science by ostention. Sci Educ. 2008;17:219–48.
Southerland SA, Scharmann LC. Acknowledging the religious beliefs students bring into the science classroom: using the bounded nature of science. Theory Into Practice. 2013;52:59–65.
Stake RE. The art of case study research. Thousand Oaks: Sage; 1995.
Winslow MW, Staver JR, Scharmann LC. Evolution and personal religious belief: christian university biology-related majors' search for reconciliation. J Res Sci Teach. 2011;48:1026–49.
Woods CS, Scharmann LC. High school students' perceptions of evolutionary theory. Electr J Sci Educ. 2001; 6:2. http://ejse.southwestern.edu/article/view/7676. Accessed 25 Mar 2020.
Zembylas M. Critical pedagogy and emotion: working through 'troubled knowledge' in posttraumatic contexts. Crit Stud Educ. 2013;54:176–89.
Zembylas M. Making sense of the complex entanglement between emotion and pedagogy: contributions of the affective turn. Cult Sci Edu. 2016;11:539–50.

Publisher's Note