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Preparing Biology Teachers to Teach Evolution in a Project-Based Approach

Abstract

This study investigates a project-based learning (PBL) approach to teaching evolution to inform efforts in teacher preparation. Data analysis of a secondary biology educator teaching evolution through a PBL approach illuminated: (1) active student voice, which allowed students to reflect on their positioning on evolution and consider multiple perspectives; (2) premature evaluative thinking actually inhibited the students' cognitive engagement with the theory; (3) discussing evolution as a false dichotomy in science, rather than a social controversy; and (4) collaborative relationships in the PBL enhanced procedural types of cognitive engagement. Implications for preparing future science teachers to structure PBL in order to foster more cognitive engagement with socially controversial topics are discussed.

Introduction

The teaching and learning of evolution in science has grown with curriculum development of related teaching materials and inclusion in state science standards (Scott & Branch, 2006). Recent education reform efforts in teacher preparation have attempted to foster the implementation of these resources by preparing educators to teach socially controversial topics, such as evolutionary theory, through the use of project-based learning (PBL) instruction (Rivet & Krajcik, 2008). In the PBL approach, teachers act as facilitators to student learning. Students have access to technology in the classroom that allows them to explore and guide their learning,

organize their work, and manage their time. Self-direction and reflection are key contributors to the process of PBL. Additionally, the benefits of using a PBL approach include deeper cognitive engagement of the subject matter, increased self-direction and motivation, and improved problem-solving abilities (Blumenfeld, Soloway, Marx, Krajcik, Guuzdial, & Palincsar, 1991; Rivet & Krajcik, 2008; Moje, Collazo, Carillo, & Marx, 2001). Active social learning of evolution is crucial to student cognitive engagement of and with the theory (McComas, 1998); cooperative interaction is at the foundation of the PBL strategy.

By structuring cognitively complex tasks, such as those afforded by PBL, a classroom teacher can provide opportunities for solving authentic problems while simultaneously enhancing student engagement (Blumenfeld et al., 1991). Cognitive engagement, defined as drawing on ideas of investment and willingness to exert the effort to investigate an issue, is enhanced when students actively discuss ideas, debate points of view, and critique each other's work (Fredricks, Blumenfeld, & Paris, 2004). A cognitively engaged student is one who not only attends to the built-in procedures of instruction but also interacts with the content of the lesson in a deep and thoughtful manner (McLaughlin, et al., 2005). By understanding when and in what ways students monitor their own learning, manage tasks, connect new ideas with previous ideas, and ask authentic questions, a teacher can better develop lessons that engage learners with evolutionary theory.

Therefore, monitoring a teacher's implementation of PBL as a pedagogical

tool for teaching about evolution, and perhaps other controversial topics in science, as well as the resulting effects on students' levels of cognitive engagement allows us to explore our own efforts in preparing teachers to effectively teach science. As teacher educators working with a large number of pre-service secondary teachers, we believe supporting them with learning how to increase students' cognitive engagement with evolution is critical. Doing this requires educating pre-service teachers about how to present curriculum in ways that not only teach the underlying principles of evolutionary theory, but also invite students to participate in a larger socio-cultural conversation on the topic.

The purpose of this study was to develop a descriptive and interpretive account of the experience of being a new biology teacher who is seeking to cognitively engage students with evolution through a PBL approach and use that understanding to improve our practices in teacher preparation. A reflective investigation of ninth-grade students' cognitive engagement in a project-based academy afforded us the opportunity to deeply analyze the strengths and weaknesses of the teacher's attempts to use PBL to teach evolution. The following questions guided our study:

- In what ways did the teacher's efforts support students' cognitive engagement with evolutionary theory?
- What aspects of the teacher's PBL pedagogical strategies fostered or hindered students' cognitive engagement?"

Background

In the following section, we employ Ronald Hermann's (2008) categories, which address evolution as a controversial issue in the science classroom, to present the literature on the effective pedagogical strategies for teaching evolution that informed our study. The main emphasis in this section is on two categories which operate on a continuum, *affirmative neutrality* and *procedural neutrality,* as they situate our efforts in contemporary understanding of teacher professional preparation in regards to this pertinent issue and aid in assuring our findings were structured to further inform those understandings.

Hermann (2008) offers the affirmative neutrality and procedural neutrality approaches in contrast to the *advocacy approach* (which Hermann contends is the most common approach to teaching evolution presented in conceptual change literature), which involves teachers demonstrating the ineffectiveness of student misconceptions. The goal in this approach is to create dissonance in hopes that students will shift their thinking to assimilate current scientific conceptions. Thus, the teacher is an advocate propelling the theory of biological evolution by demonstrating faults with students' alternative thinking. Advocacy approaches do not always allow students the opportunity to reconcile aspects of evolution with their personal worldviews and varying epistemologies. Students may consequently negate the theory because they do not see its relevance to their lives.

The *affirmative neutrality* and *procedural neutrality* approaches, however, are used as a continuum to explore controversial issues such as evolution from multiple points of views. In these approaches, teachers present multiple perspectives and competing epistemologies. Because the teacher remains in control of classroom discussion, the affirmative neutrality approach does not always allow students to investigate the alternate views to any depth. Thus, students are not able to explore varying viewpoints, rather they only briefly hear from the teacher that they exist (Hermann, 2008). Student discussions, then, can be limited by the teacher if they are seen as hindering the teaching of the theory. However, while acknowledging the social nature of the controversy, affirmative neutrality permits recognition of multiple ways of knowing. The *procedural neutrality* approach is slightly different from the affirmative neutrality approach in that it trends toward eliciting a variety of perspectives on evolution from the students, rather than simply being explicated by the teacher. This approach serves to both increase students' control as well as their opportunities to discuss the issues. In this way, students can conduct their own research and voice their own reflections as they learn about evolutionary theory. Procedural neutrality gives students freedom to explore varying ways of knowing without advocating one particular epistemology.

The affirmative and procedural neutrality continuum to evolution education requires the teacher to provide students with opportunities to explore evolutionary theory from multiple perspectives, which may increase their acceptance of it (Hermann, 2008). Important here is that the teacher exposes the students to various points of view; thus, students are not presented with evolution and creationism as opposing entities as may be the case with the one-sided stance of advocacy approaches (Scott & Branch, 2006). In contrast to the affirmative neutrality approach however, the procedural neutrality approach permits consideration of varying epistemologies and exploring multiple ways of knowing without advocating one particular view. There is a clear need for more research on utilizing effective pedagogical strategies to teach evolution, specifically those aligned with the affirmative and procedural neutrality approaches. Though science educators call for evolution instruction that allows students to voice their opinions, identify misconceptions, and learn about the nature of science, empirical research needs to be conducted to further explore these approaches (Hermann, 2008).

The teacher of interest in our study situated himself in the procedural neutrality approach to evolution instruction as defined above, and claimed his instructional unit was less about changing student conceptions and more about encouraging them to consider the nature of science and the social controversy of evolutionary theory, thus leading to enhanced cognitive engagement with the theory. PBL, as his pedagogical choice to teaching evolution, underscored the aims of the procedural neutrality approaches by democratizing learning such that students were allotted the space to explore multiple perspectives as well as be reflective about their own learning. Additionally, PBL afforded opportunities for a great deal of cooperative learning and self-direction, which the teacher saw as instrumental components of meaningful engagement with the theory of evolution.

Methodological Design

Our methodological approach was influenced by our belief that if we are to create and implement successful teacher development programs, we must possess a deep understanding of the current issues facing a science classroom teacher (Anderson, 2007) and that such an understanding emerges as the involved parties negotiate meaning within the process of problem solving (Greenwood & Levin, 1998). We believe that we, as science teacher educators, cannot remain disconnected from teachers and classrooms. We must take steps to assure that teachers remain at the center of our inquiry (Greenwood & Levin, 1998). This case study was part of a larger research program aimed at providing baseline knowledge of the changes teachers and students experience in implementing project-based curriculum. Here, we sought to understand how a teacher from a project-based learning (PBL) school framed evolution instruction and how that instruction impacted the students' cognitive engagement with the theory of evolution.

Context. The classroom teacher was chosen due to his unique position as a biology teacher at a project-based academy. Although he was a first year teacher, grappling with effective ways to teach evolution was not unique to

him. To better connect our research to the concerns of teachers exiting teacher preparation programs and entering the teaching profession, the teacher was selected from a recent pool of graduates. Mr. Shepherd (pseudonym) entered the post-baccalaureate teacher certification program with a dual Bachelors Degree in biology and chemistry, and graduated with a Masters Degree in Education and teacher certification in both biology and chemistry.

At the time of this study, Mr. Shepherd, a first year science teacher, was teaching 70 ninth-grade students enrolled in his biology course. Mr. Shepherd was teaching in a "21st Century Skills" Academy housed in a large urban Midwest high-school. In this teaching position, he was expected to develop PBL units to meet the goals of academy and academic standards. At the time of the study, Mr. Shepherd had already completed two quarters of teaching for the school year, having taught several PBL science units. Two block-schedule classes of 110 minutes meeting Monday through Friday were selected by the teacher to participate in this study because of their unique interdisciplinary and project-based focus. Each class contained 35 students. Of the school's total 1,632 students (2007-08 school year), 83% were white, 10% were black, 4% were Hispanic, 1%

were Asian, and 2% were multiracial. Additionally, 43% of students qualified for free lunches. These statistics were also reflective of the student population participating in this study.

Mr. Shepherd was selected as a subject in this study because he was the teacher responsible for the learning components involving science content standards and, despite his limited time as a classroom teacher, had a bachelors degree in biology and chemistry, training in project-based science teaching, and had successfully taught several PBL biology units to this student population. In our view, his practices on a PBL evolution unit were worth careful analytical examination. He understood it was necessary to teach the science content standards, uphold the ideals of the project-based reform initiatives at his school, and encourage students to think beyond the scientific explanations of biological change. At the time, he expressed apprehension and concern about not offending his students who he perceived as being mostly skeptical about evolution. Nonetheless, he understood the need to teach evolution and often referred to the state standards as a justification for why he was teaching it to his sometimes-resistant students. Though students seemed to understand the constraints their teacher faced, some

of them did not feel it was a good idea to discuss such a contentious issue.

Mr. Shepherd required his students to work throughout the year on cooperative, computer-based projects that incorporated biology standards. In the classroom, each student had access to his or her own computer. Even though the students seemed to struggle with content mastery and team dynamics using the PBL approach, they were experienced with project formats and expectations. Students were also experienced with our presence as researchers, as we had been observing and interviewing them throughout the school year in relation to a larger study. Though the project outlines for each unit changed in terms of outcome expectations, grading and homework guidelines remained standard operations throughout the course.

For the evolution PBL unit, the students were organized into groups of three. The teacher's goal for the three-week PBL unit (see Table 1) was for students to research evidence for and against varying aspects of evolution and to present their thoughts on how the theory should be taught in American high school biology classrooms. Thus, students were to address varying lines of evidence to evaluate how they should be approached in instruction. Individuals within each team were asked to argue

Table 1 *Evolution discussions co-facilitated by Mr. Shepherd.*

Discussion	Teacher Role	Activity
Research	*Mr. Shepherd:* probes students to research various topics on-line and collect evidence for final presentation to the class.	*Description:* Students research on-line evidence (1) for and against varying aspects of evolution and (2) to present their thoughts on how the theory should be taught in American high school biology classrooms.
Article Debate	*Mr. Shepherd:* serves as facilitator and encourages students to share their thoughts and opinions.	*Description:* students share their reactions to a recent newspaper article entitled "Scientist says creation debate too hostile" (Roberts, 2007)*
Mini Lecture	*Mr. Shepherd:* serves as a lecturer by introducing biological concepts, providing illustrative examples, and answering students' questions.	*Description:* Mr. Shepherd (1) provides students with background information on the scientific perspective on the origin of life, introduces and illustrates several evolutionary concepts such as biological change, micro-evolution, macro-evolution, species, adaptation, and mutation; (2) facilitates an activity about the nature of science**.
Chalk Talk	*Mr. Shepherd:* introduces discussion questions at the beginning and reacting to students' responses at the end.	*Description:* Teacher (1) places 4 questions on poster boards around the room***; (2) gives each student 5 post-it notes to anonymously respond to questions; (3) nominates students to read post-it responses aloud; and, (4) facilitates whole-class discussions and comment on students post-it responses.

* Prior to participating in the debate, students were asked to read and reflect about the article (available on the classroom computers) in small groups.

** Mr. Shepherd highlights that evidence is subject to interpretation by writing the two sets "A l3 C" and "l2 l3 l4" on the board and having different groups of students read and then compare their interpretations of middle term. Students who look at the first set interpret the middle term as the letter B, whereas students who read the second set interpret the middle term as the number thirteen.

*** Poster board questions: (1) "What should schools teach about evolution?" (2) "Do you agree with Darwin's theory?" (3) "Questions about evolution?" (4) "Are faith and science incompatible?"

for or against their chosen topic. Topics ranged from researching evidence for evolution to controversy over the age of the Earth.

Data collection. The teacher's instructional efforts, as well as the students' cognitive responses to those efforts during a three-week project-based evolution unit were the main data sources for this study. Our collaboration with Mr. Shepherd consisted of daily discussions of the project and the students' responses in an effort to inspire reflection on his instructional decisions. Our role as observers was to audio- and video-tape both classes, take field notes, and collect salient artifacts from the unit such as teacher documents and student written responses. In an effort to explore not only what instruction was being conducted, but also to investigate the students' responses to those curricular designs, we collected student assessments (quizzes, tests, and final presentations) and daily journals. As part of the project-based curriculum throughout the year, students were asked to reflect daily on a topic related to the unit at the beginning of class. For example, on the second day of instruction in the evolution unit, students were asked to individually read a short article about the inappropriateness of creationism in the science classroom and reflect in their on-line journals on their opinions about the article. All group discussions were audio-recorded and these recordings were transcribed, with each student assigned a pseudonym.

Because the focus of this study was guided by the impacts of the teaching process on the cognitive engagement of the students, we begin by defining how we view cognitive engagement and how it was evaluated. Rather than utilizing students' achievement as an indicator of cognitive engagement, we employed qualitative methods to acknowledge and explore how the students engaged with the content in ways that may not have been measured in summative assessments used to evaluate achievement. Cognitive engagement is seen as drawing from both psychological and cognitive dimensions: it can "range from simple memorization to the use of self-regulated learning strategies that promote deep cognitive engagement and expertise" (Fredricks et al., 2004, p.4). The construct is linked to motivation and strategic learning, and is displayed when students monitor their own comprehension, manage tasks, connect new ideas with previous ones, and ask authentic questions.

Gauging the levels of cognitive engagement inspired by the instructional aims of the unit, the student perspective was essential in determining the effectiveness of the teaching process. Thus, not only were the journals and the recordings of group interactions important in evaluating cognitive engagement, but we also conducted student interviews (N=30) on the second to last day of the unit. This time was suggested by the teacher in order to minimize students' distractions when completing their presentation preparations. At the time of the interviews (see Appendix A for protocol), the majority of students were finished with their project and planned to present on the following day. To gauge cognitive engagement, we followed suggestions to inquire about strategies students used to set goals, plan, organize their study efforts, and monitor and/or modify their cognition. We also asked about how they managed effort and exercised volitional control to concentrate and complete work effectively (Fredricks et al., 2004).

Analyzing the data. The measurement scales for cognitive engagement vary among researchers, but common items include: being committed to cognitive engagement with the work (in contrast to wanting to get a good grade or wanting to look smart), persisting in work despite difficulties, exchanging ideas with classmates, using analogies, relating new knowledge to existing knowledge, actively monitoring comprehension, using strategies such as elaboration or organization, employing high-level evaluation and authentic questioning, and self-regulating learning (Lee & Anderson, 1993; Lee & Brophy, 1996; Gamoran & Nystrand, 1992). These indicators of cognitive engagement were used to guide our analysis.

In contrast, procedural engagement (managing tasks, planning, suppressing distractions, organizing material) is centered on trying to complete task requirements, which lasts only as long as the task itself. This can be seen when students avoid effort to gain quick information for the completion of the assignment.

The interviews with the students (see Appendix A), which focused on cognitive dimensions of their learning and allowed students to elaborate on their perspectives of the unit, as well as the classroom video/audio and field notes were transcribed and analyzed using a rubric of expected constructs. The context, example, frequency yielding total percentages of students exhibiting cognitive engagement during total class time, and data source of these codes were also noted. Using NVivo (qualitative data analysis software), the raw audio, video, and transcript data were open coded using a rubric of cognitive engagement (see Appendix B), which helped to categorize codes that could then be grouped together to determine the frequency of occurrence in the data.

At any time, if the rubric did not include a necessary code for a data point, a code was added to the rubric and previous data were then re-coded to include any additional emergent codes; thus, the coding was an iterative process. As well, codes were not always mutually exclusive and thus multiple codes may have been used for the same data point. Once a saturation of codes was reached, we conducted a thematic analysis (Aronson, 1994) on all transcribed data sources to explore the ways in which instruction was linked to the students' cognitive engagement. All data that fit under similar patterns was first identified and placed together. For example, discourse on "both sides" of evolution was placed under a pattern of "polemic debate." The next step was to combine and catalogue related patterns into sub-themes. Themes are defined as units derived from patterns such as "conversation topics, vocabulary, recurring events or activities, meanings, or feelings" (Taylor & Bogdan, 1989, p.131). Themes that

emerged from the students' and teacher's stories were pieced together to form a comprehensive picture of their collective experience. As such, both the percentages of cognitive engagement and the interview and observational data were analyzed inductively to build a naturalistic account (Lincoln & Guba, 1985) of the effects of the instructor's evolution teaching strategies.

To address issues of validity with the coding of the data, the extent to which the students seemed honest and sincere in the interviews was evidenced by some of them exposing their own personal beliefs concerning religion and belief in God. Questions that were non-leading allowed students to express their views on evolution without fear of judgment. Thus, the students felt open to discuss these private values. Additionally, checks for consistency were employed on recorded interviews and data were transcribed verbatim. Peer de-briefers (discussions with faculty science educators to provide feedback concerning the accuracy of interpretations of the data) were used to hone interpretation of the various codes. Paraphrasing techniques used by the interviewer also allowed students to alter or correct interpretation during the interview.

Limitations. There were complications in using observational data to measure cognitive engagement because cognition must be inferred from behavior. However, time and instructional goals in the classroom may not allow for the recognition of students' true levels of cognitive engagement with the task (Fredricks et al., 2004). Limitations to this study were also evident in that a glimpse into only one double classroom certainly limits generalizability of the findings. However, our goal here was not to generalize, but to learn from a new teacher from whom we could attain valuable insights into our teacher preparation tendencies. As well, the analysis of cognitive engagement is inferred from behavior, and it is difficult to assess self-regulation and intentions behind behavior.

Additionally, another important limitation was our characterization of a teacher's oral framing strategies based exclusively on data from video-recordings of three relatively short evolution discussions in a single classroom setting. Because of this limited scope, many relevant issues remained unaddressed in our exploratory analysis of evolution instruction, including the extent to which the oral framing strategies reported in this study can be effectively and appropriately adopted by teachers to facilitate evolution discussions across varied education contexts (conservative, liberal, suburban, rural, and urban); how teachers' oral framing practices relate to their evolution understandings (content knowledge, acceptance, and epistemological stance); and the impact of teachers' oral framing of evolution discussion on learning outcomes (e.g., students' conceptual understandings, acceptance of evolution, views of the nature of science, epistemological positions, and views of evolution instruction). Additional studies will be necessary to explore these aspects of teacher-led evolution discussion.

Findings

With regards to the research questions, "In what ways did the teachers' efforts support students' cognitive engagement with evolutionary theory? and "What aspects of the teacher's PBL pedagogical strategies fostered or hindered the cognitive engagement?" we found that: (1) the teacher's emphasis on student voice allowed students to reflect on their positioning on evolution and to consider multiple perspectives; (2) by engaging his students in evaluative thinking too soon, the teacher inhibited their cognitive engagement of the theory; (3) by presenting evolution as a polemic and false dichotomy in science, rather than a social controversy, the teacher appeared to inhibit student cognitive engagement; and (4) the teacher's use of collaborative social relationships in the PBL enhanced procedural types of cognitive engagement. These findings are presented and explored below and examined in light of teacher development in the implications section.

The teacher's emphasis on student voice allowed students to reflect on their positioning on evolution and consider multiple perspectives.

By providing students with several opportunities to discuss their thoughts on evolution, this teacher engaged them in high-level evaluative discussions. He facilitated student involvement in several discussion forums where students could assert their opinions, as well as a chalk talk[1] in which they could respond to each others' opinions through post-it notes around the room. Students claimed they appreciated the chance to position-take, hear multiple perspectives, and contribute to the classroom debate, all of which are indications of enhanced cognitive engagement. As well, students acknowledged an appreciation for learning from each other:

> My personal thought on debates and things is that without these debates…If there's no debates, knowledge becomes stagnant then there's no spreading of knowledge, people don't share ideas. (Vincent, class discussion)

The interchange of teacher and student roles in the PBL was evident through watching the classroom interactions. As the students were conducting their own research related to their assigned position on the topic and making decisions about what was important to include in their presentations, Mr. Shepherd moved around the room asking probing questions and assisting students in their research. Students appreciated Mr. Shepherd's attempt to remain neutral in the debates that ensued in the classroom. When asked about their feelings on how the evolution PBL was taught, one student, Jack, said:

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[1] *Chalk Talk*: Teachers (1) place 4 questions on poster boards around the room; (2) give each student five post-it notes to anonymously respond to questions; (3) nominate students to read post-it responses aloud; and, (4) facilitate whole-class discussions and comment on students post-it responses as a springboard for discussion.

Yeah, um, I just think for him, he's [Mr. Shepherd] not really telling us, he's not like making us believe God made us, because I really don't- I don't know, I really don't believe God made everyone. I think it was a cell that made the animal. I like the fact that he is not telling us what to believe. If he was like- no, God made us, God made everyone … then it would be kind of wrong. (Interview)

Data analysis indicated that the students were engaged in: asking clarifying questions (9% frequency as coded from all data sources), inquiry-based questions (9%), summarizing (2%), suppressing distractions (5%), concentrating (7%), going beyond requirements (2%), exchanging ideas (8%), connecting ideas (2%), elaborating (5%), and using analogies (1%) to describe what they were learning. These codes for cognitive engagement allowed us to see that student voice was emphasized in the PBL, which allowed students to reflect on their positioning on evolution and consider multiple perspectives, a goal of the affirmative procedural neutrality approaches to teaching evolution.

By engaging his students in evaluative thinking too soon, the teacher inhibited their cognitive engagement of the theory.

Mr. Shepherd devoted a great deal of time throughout the unit to allowing students to voice their thoughts and reflections on evolution. However, students were not connecting their ideas nor problem-solving about evolution. Additionally, there was a tendency toward relativistic thinking by Mr. Shepherd. Throughout the unit, all viewpoints were equally valued with no regard for the need for evidence-based argumentation or reflective- based scientific reasoning:

Just because someone interprets the evidence differently doesn't mean they're stupid or wrong AND I think there will be some good practice in doing that and hopefully looking at the evidence yourself and I will divide you into teams to look at the evidence and you can discover what you think. (Mr. Shepherd, class instruction)

Here Mr. Shepherd asserts the relativistic stance he took throughout the entirety of the unit. Thus, students often referenced non-scientific evidence for their statements. For example, one student explained during a class discussion:

God was in the background guiding evolution along. So evolution went through all of its stuff, but God was there, you know, guiding this [evolution] through. (John, class discussion)

Lack of guidance and scaffolding in evaluative thinking may have contributed to the students' limited knowledge and cognitive engagement in their learning of evolution through this project. No time was spent on uncovering potential biases in information found on-line or other sources (e.g., books, peers, or other adults).

As such, low levels of cognitive engagement and information processing were seen in the retrieval of factual information when students sought evidence for their positions; though little synthesizing (2% connecting ideas, 2% summarizing) of that information was expressed, participants rarely interpreted the relevance or application of that knowledge (5% elaborating). Thus, a great deal of the material being investigated by students was not consistent with scientific views of evolution. The following quote illustrates this point.

I think if there's ever a way to disprove a mightier being, God, or if there's any way to ever disprove any type of evolution, then nobody would believe it anyway because religion has been based on Creationism for thousands of years and stuff. Everybody would think their life has been based on a lie and they're not going to believe it anyway. (Ben, interview)

Though students still held naïve misconceptions about the basics of evolution, the teacher tried to propel them into higher level thinking before they understood these concepts; thus, indicating his own incorrect assumption that over time using this approach would naturally lead to cognitive engagement.

The teacher's emphasis on the controversy did not allow for exploration of evolutionary theory itself. In fact, as a result of students' lack of cognitive engagement of evolutionary theory, the code of "students' realizing where their knowledge was lacking" was iteratively added to our list of indicators for cognitive engagement. Our analysis of cognitive engagement was based upon definitions found in the education literature; however, we soon realized that an obvious indicator of cognitive engagement, or lack thereof, was needed. In our discussion with the students we repeatedly found they had a limited cognitive engagement of evolutionary theory. The following quote was selected as a representation of the students' general lack of cognitive engagement of this concept:

Like how horse's develop into giraffes, or something like that. And that's how I learned in my 7th grade class- he said that horse's have longer necks to survive so they can eat the leaves, but I don't think he knew what he was talking about. But then, it doesn't like, once you question evolution, it doesn't explain cause their hearts are beating so fast, giraffes hearts' are beating so fast to give that blood pumping up that long neck, like if they turn over, all their blood will rush and they could die, or I don't understand, but they have like a spongy thing in their head to soak up all the blood. How do you explain that? How do you explain that through evolution? How did that develop? (Juliette, interview)

It was thus evidenced that students did not have an adequate understanding of the process of evolution and still possessed many questions as to how the process of change in species occurred, despite their being asked to make evaluative judgments about how the theory should be taught.

By presenting evolution as a polemic and false dichotomy in science, rather than a social controversy, the teacher inhibited students' cognitive engagement of the theory.

The teaching process, which focused on students arguing for and against various components of evolution, led to polarization and seemed to hamper their cognitive engagement of the theory. For example, one student stated,

> I think it is important because people want to figure out what part is true, if Darwin's theory is true or like your opinions [are true]. Like if his opinion is right or if your own opinion is right and what we believe in. (Libby, interview)

Students seemed to perceive the theory of evolution as a belief system with which they needed to either agree or disagree. There was no discussion about what a scientific theory is or how it develops in science, as inferred from the following quote.

> Scientists today are so eager to prove that the theory is true of evolution, that they are willing to fake evidence. We don't know if they fake it on purpose or if they are doing it for the money or if it was an honest mistake (Kate, class discussion)

Therefore, when students were asked what the meaning of a scientific theory was, statements such as the one above made it clear they held misconceptions about the aims of science as a discipline.

In classroom discussions, such as the chalk-talk reflections or in journaling about an inflammatory on-line editorial[2], evolution and creationist accounts of life were often found to be pitted against one another requiring students to choose a side based on personal opinion rather than scientific evidence as indicated in the following quote.

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[2] *On-line Article*: Students share their reactions to a recent newspaper article entitled "Scientist says creation debate too hostile" (Roberts, 2007).

Instead of trying to fight either way, people are going to have their own opinions and no matter what you say, think, or do their opinions are not going to change. (Aaron, class discussion)

However, other students seemed to walk away with a different point of view on the instructional approach, indicating that they felt they were encouraged to explore and consider multiple perspectives. For example,

> Well, throughout the whole article it was saying how the public was not up to speed. We don't just need one side of the story from the scientists; we need to tell it from both sides. We can make our opinion based on both sides. (Claire, class discussion)

Throughout all of this, everything everybody's been saying has either been on one side or the other side. There's an idea, well, not exactly mine I got it from somewhere else, that what if evolution was how instead of why? (Daniel, class discussion)

The structure of the PBL project itself, asking students to form opinions on the way evolution should be taught in the American high-school classroom, centered the focus on the contentious social aspects of the theory rather than the tenets or usefulness of the theory. Additionally, setting up team roles as argumentation for and against aspects of evolution set the stage for the dichotomies that persisted throughout the unit. In their final presentations, students presented evidence found on-line to argue their positions, yet there was no attention paid to the trustworthiness of the source of information or potential biases in the accounts offered.

The teacher's use of collaborative social relationships in the PBL enhanced procedural types of cognitive engagement.

Mr. Shepherd used collaborative work extensively throughout this unit. The data analysis revealed that his students were often distracted by the off-task behavior of their peers. When asked if

her group was ready for the culminating presentation at the end of the unit, Kate claimed:

> Um, I really haven't done anything and I've been like working all the time. It's the thing about [this school] that really gets on my nerves is because they don't tell you what to do, you have to figure it out by yourself. And then like when its crunch time when the project's due- its due today, and I don't have like anything done. And both of my group members don't work so I have to do all of their work again. (interview)

Data analysis indicated that the students, in terms of peer interactions, were engaged in suppressing distractions (5%), planning (10%), organizing (13%), concentrating (7%), managing tasks (13%), goal setting (9%), and exchanging ideas (8%); however, very limited instructional time was spent analyzing and synthesizing information. Thus, collaborative work presented the need for a great deal of procedural engagement. The PBL unit fostered some cognitive engagement, but was quickly lost to a strategic or ritual compliance. Despite the students having participated in several PBLs throughout the year, a great deal of time was spent on managing tasks. For example, one student said:

> Like dealing with the other group members- one of them, Libby, is somewhere, she keeps walking around. That's been frustrating dealing with the other group members. I'm doing most of the work. We'll be ready [for our presentation], but I'll have to get them under control. (Sawyer, inteview)

In fact, 46% of the total cognitive engagement coded was the management of procedures, the completion of tasks, and the planning of the project. Though students were engaged in voicing their opinions about the topic, active analysis of varying viewpoints gave way to hurried completion of the project. While cooperative skills were essential in this

unit, we found it worthy to note the lack of time actually devoted to content.

That being said, students were quite well-versed at this point in the semester in the "Classroom as an Office" style of learning. Thus, routines in the classrooms were palpable. Students needed little direction in cognitive engagement in their tasks for the day. Expectations for projects always adhered to the same guidelines, and project outcomes tended to range within a set standard of presentation styles (PowerPoints, instructional games, lecture of findings, poster boards, etc…). Routines were at the heart of this operation and all participants not only relied on those structures, but were limited to roles within those structures. Students required little guidance as a whole to work as a team. They entered the classroom and went to work when they were ready; they monitored their time; and they decided on their responsibilities to their group members. The teacher was similar to an office manager, who got involved only if students were off-task or when asked for assistance. Though the teacher had the ultimate say in what happened in the classroom, students were working primarily on their own and independently.

Implications for Teacher Development Efforts

Based on our findings of Mr. Shepherd's PBL aimed at a affirmative and procedural neutrality approach for teaching evolution, we now reflect on lessons learned from this experience to better understand how we can prepare teachers to teach evolution using PBL in a more cognitively engaging manner. It is essential that we prepare teachers to teach students not only the social nature of the topic of evolution but also the accurate scientific principles of evolutionary theory.

Facilitating effective student discussions on evolution. Hess (2002) claimed that participation in discussions enhances students' willingness to engage in the political world, and improves their critical thinking and interpersonal skills. Though we found Mr. Shepherd completed the teacher preparation program

prepared in a manner that allowed him to effectively invite participation into the social discussion of evolution and present an authentic inquiry into the teaching of the content of this topic, his desire to have the students engage in high-level evaluative thinking before cognitive engagement in basic evolutionary concepts and the nature of science resulted in his students not understanding the topic to the degree needed to participate in the evaluation of concepts as required for the project (Farber, 2003; Khourey-Bowers, 2006). In other words, while Mr. Shepherd's pedagogical approach had the students actively engaged in discussions, they did not walk away with an accurate understanding of the scientific principles underlying the theory of evolution.

Parker (2003) asserted that deliberation is particularly important for strengthening relationships across differences and teachers should avoid the tendency to set up adversarial relationships that do not necessarily lead to a fuller understanding of controversial issues. While a contentious atmosphere quickly dissipated and students indeed seemed to feel comfortable expressing their own opinions and reflections on the social controversy of evolution, strides made to understand the theory and usefulness were significantly lacking. The use of on-line sources which were not critiqued for biases and the lack of scientific argumentation gave way to relativistic positioning of opinions as the basis for discussion. Without the help of a mentor who has a higher level of cognitive engagement of the scientific concepts and who can scaffold student learning of these concepts, an individual may find difficulty in achieving independent competency in learning (Gredler, 1997).

If we are going to prepare teachers to teach students about evolution and have them recognize it as a well-supported scientific theory, we need to address the widely-held misconceptions students harbor about evolution and the nature of science. Evolutionary theory is not based on beliefs and attempts to analyze it using non-scientific considerations fail to illuminate how the theory has been useful as

an explanatory force. Smith (1994) contends that any classroom discussion that precedes the teaching of evolution, and thus sets the stage for an understanding of evolution as science, should deal with the nature of science and how it differs from other disciplines. He concluded that evolution instruction is challenging because it is both conceptually difficult and because it may not fit with students' worldviews, histories, and perceptions. In this classroom, Mr. Shepherd did not explicitly or reflectively teach the nature of science, which as research suggests (Farber, 2003; Khourey-Bowers, 2006), could help students understand how science is developed. As well, teaching about the nature of science could assist teachers and students in reflecting on their own epistemic understandings of the world.

Designing, implementing and assessing in PBL. We should also prepare teachers to consider several factors related to PBL project design and controversial issues, including not only the inherent interest and value of the problem to students, but also students' level of competence to engage in and complete the project and a focus on learning for cognitive engagement rather than for final outcomes and grades. Construction of the driving question in a PBL is critical to students' motivation and engagement; the question should not be so constraining as to predetermine the project's outcomes, nor should it be so broad that it would overwhelm and de-motivate students' attempts to learn and engage in problem-solving. The problem statement Mr. Shepherd developed asked students to take the position of a teacher, which was too big of a leap for them to consider before properly building the foundation of understanding of the theory. We should prepare future teachers to be very clear about learning goals and outcomes, and design appropriate activities that engage students in learning that inspire them to move among various levels of cognitive engagement. It is problematic to propel students into higher-level synthesis and evaluation of complex topics such as evolution without the proper scaffolds. Students need to understand

and be able to apply their conceptual knowledge so that evaluative judgments can be grounded in understanding.

Providing students opportunities to collaborate is a key feature of PBL (Hmelo-Silver & Barrows, 2006; Rivet and Krajcik, 2004). We found that although collaborative learning was a part of this teacher's preparation, he was not prepared for the complexity of collaborative work required of PBL. Being prepared to model effective collaboration skills and facilitate group negotiation is necessary in such pedagogical approaches as PBL, and may also provide more opportunities for promoting cognitive engagement among the students as called for in the research literature (Fredricks et al., 2004). Although students were working collaboratively by managing their projects and assigning tasks, their focus was on procedural engagement rather than stimulating the critical thinking aspects of cognitive engagement.

The summative assessment prepared for this PBL project, which was the presentation students created on their individual topics (see Appendix C for evaluation rubric), did not reflect the attempted high levels of engagement sought throughout the PBL. Students were asked to voice their opinions on how evolution should be taught as well as argue for and against various lines of evidence for the theory; however, the rubric is based on the content standards. Mr. Shepherd seemed to assume students would naturally learn the content standards through their exploration despite this not being the explicit instructional focus of the unit. Overall, assessment included low-level knowledge, comprehension, and application questions despite the higher order thinking that was emphasized in the PBL. Our work with teachers should include discussion about proper assessment strategies before, during and after a project. For example, when new material is being introduced, early formative assessments should include ascertaining that the basics are present before moving on. When teachers decide to measure beyond the knowledge level,

the appropriate level for items depends on the developmental level of students. Researchers believe that teachers should test over what they teach in the same way that they teach it (Bloom, 1956). In this evolution PBL unit, assessment of concepts did not correspond to instructional goals and thus the transfer of conceptual understanding did not materialize at the level the teacher expected.

In terms of formative assessment, Mr. Shepherd had the students journal daily about their cognitive engagements; however, those responses were not being used to modify his instruction. It is recommended that we prepare teachers to read and use these daily assessments to guide their instruction and provide proper scaffolds for student cognitive engagement, as well as to embed formative assessment prompts, such as journal questions or written reflections, throughout the entirety of a PBL unit. These can include student-teacher interactions, practice worksheets, peer counseling, guiding questions, job aides, project templates, relevant in-class discussions, or follow-up questions about what students have learned. This will allow teachers to stay connected to what the students are processing as they independently explore on-line resources in the context of PBL.

Conclusion

In conclusion, the findings from this study give teacher educators a better understanding of how to prepare teachers to teach science, and especially controversial scientific topics, using a PBL approach to enhance students' cognitive engagement. From this study we learned that teachers need to know how to stimulate effective student discussion and how to design, implement, and assess during PBL experiences continuously throughout all projects; especially in regards to socially controversial topics such as evolution. All of the recommended strategies for teaching evolution promote student-centered instructional methods and seem to suggest that a teacher's role is to support each student's own construction of knowledge. The PBL model offers a pedagogical structure to teachers

to embed important components such as collaboration, self-regulation, and multiple perspective-taking, which can contribute to increases in cognitive engagement (Fredricks et al., 2004).

This example can also serve as a structure to support the recommended continuum model of affirmative and procedural neutrality approaches to teaching controversial issues. Mr. Shepherd's evolution teaching practices were consistent with procedural neutrality, an instructional approach advocated by Hermann (2008) wherein the teacher acknowledges the controversial nature of evolution by providing students with an opportunity to express their opinions and to participate in in-depth and open discussion of a variety of perspectives on evolution. Instead of attempting to promote student adoption of the scientific perspective (advocacy approach) or neutrally lecturing about different standpoints on evolution (affirmative neutrality approach), the teacher facilitates extended discussions in which he neutrally elicits different viewpoints from students and instructional materials without suggesting that alternative views of evolution are invalid, inferior, or irrational.

However, we need to emphasize the care that should be taken to avoid relativistic discussions that hinge on student opinion rather than thoughtful consideration of the evidence or usefulness of the theory. Teaching the social nature of evolutionary theory can and should be done, but it needs to be untangled from the tenets of the theory itself and should come after students have an adequate foundation of understanding of evolution and can articulate what the nature of this scientific theory is. Though it is unlikely that there will ever be a successful one-size-fits-all approach to teaching controversial issues in science, PBL could help teachers to engage the students with evolutionary theory and, if structured properly, promote student learning of the concepts.

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Appendix A: Student Interview

1. Overall, how do you feel this last project went? Specifically, how do you feel about the project-centered approach for learning about this topic?
    →   What about the project did you like?
    →   What about the project didn't you like?

2. What aspects of the topic explored do you feel like you understand? What are you still confused about?
    →   What science questions do you still have?

3. How well do you think you did overall with this topic?
    →   Did your performance meet your expectations?
    →   How was your performance assessed? Do you think it reflects your actual performance?

4. What is it about the project approach fits with how you like to learn? Comment on the following:
    a. Working in groups? Minimizing distractions?
    b. Technology?
    c. Final Product? Setting goals and organizing tasks?

5. What challenges did you face working through this topic (for example, the way the content was organized, instructional approach etc.)
    →   How did you deal with the challenges?

6. Do you think you were as engaged with this activity as you should have been? Why/Why not?

7. Can you tell me a little about the assessment in this new approach? Do you think teachers are able to see what you do/do not know? Do you think your final grades reflect what you do know?

8. What do you like about the project-based approach to learning evolution? What do you not like?

9. How did this approach to learning help you understand evolution?

10. What have you learned about evolutionary theory and its applications in life?
    →   What is evolution?
    →   What is a theory?
    →   What is the evidence for evolution?
    →   In what way is evolution important to life?

11. Do you feel prepared to take a test on this topic? Why or why not?

12. Tell me what you know about the nature of science. What questions do you still have?
    →   What does science offer to our understandings of the world?

13. How well do you think you did in this project? Why?

14. How would you improve upon this lesson if you had the chance to do so?

Appendix B: Data Analysis Rubric

Cognitive Engagement	Frequency
Suppressing Distractions	5%
Connecting Ideas	2%
Asking Inquiring Questions	9%
Asking Clarifying Questions	9%
Planning	10%
Goal Setting	9%
Concentrating	7%
Using Analogies	1%
Going Beyond Requirements	2%
Persisting Despite Complications	0%
Managing Tasks	13%
Problem Solving	0%
Summarizing	2%
Elaborating	5%
Organizing Material	13%
Exchanging Ideas	8%
Realizing where knowledge was lacking	5%

Appendix C: Evolution Project Rubric

Course: Bio-Lit
Project: The Great Debate   (Points _____/100)

STUDENT:
DATE:

CRITERIA	AT RISK (In Danger of Failing)	EMERGING (On the Road to Success)	ADVANCED (Demonstrates Exceptional Performance)
B.1.27 Explain that the similarity of human DNA sequences and the resulting similarity in cell chemistry and anatomy identify human beings as a unique species, different from all others. Likewise, understand that every other species has its own characteristic DNA sequence. B.1.30 Understand and explain that molecular evidence substantiates the anatomical evidence for evolution and provides additional detail about the sequence in which various lines of descent branched off from one another. B1.31 Describe how natural selection provides the following mechanism for evolution: Some variation in heritable characteristics exists within every species, and some of these characteristics give individuals an advantage over others in surviving and reproducing. Understand that the advantaged offspring, in turn, are more likely than others to survive and reproduce. B1.32 Explain how natural selection leads to organisms that are well suited for survival in particular environments, and discuss how natural selection provides scientific explanation for the history of life on Earth as depicted in the fossil record and in the similarities evident within the diversity of existing organisms. B1.33 Describe how life on Earth is thought to have begun as simple, one-celled organisms about 4 billion years ago. Note that during the first 2 billion years, only single-cell microorganisms existed, but once cells with nuclei developed about a billion years ago, increasingly complex multicellular organisms evolved. B1.34 Explain that evolution builds on what already exists, so the more variety there is, the more there can be in the future. Recognize, however, that evolution does not necessitate long-term progress in some set direction. B1.35 Explain that the degree of kinship between organisms or species can be estimated from the similarity of their DNA sequences, which often closely matches their classification based on anatomical similarities. Know that amino acid similarities also provide clues to this kinship. B1.36 Trace the relationship between environmental changes and changes in the gene pool, such as genetic drift and isolation of sub-populations. Standard 2 Students gain understanding of how the scientific enterprise operates through examples of historical events. Through the study of these events, students understand that new ideas are limited by the context in which they are conceived, are often rejected by the scientific establishment, sometimes spring from unexpected findings, and grow or transform slowly through the contributions of many different investigators.	Any failure to meet one of the "emerging" standards will count as a mark in this category	• Explains one line of evidence • Gives at least two examples of this evidence. • Explains how this evidence is gathered and analyzed. • Communicates and explains at least one way that this evidence is used to support macroevolution (common descent). • Communicates and explains at least one way that this evidence is used to argue against macroevolution (common descent). • Uses at least three pictures (when appropriate – see teacher if you have questions) • Group is well organized in the way that information is presented – the individual parts work together to build on each other and don't repeat the same information over and over.	In addition to meeting the emerging criteria … • Gives at least three examples of the evidence • Comes up with an interesting, creative, or interactive way to present the material to the class. • Communicates and explains at least two arguments for common descent. • Communicates and explains at least two arguments against common descent. • Uses more than three pictures, and uses them in a way that helps to explain the material more effectively
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