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CREATING A PROBLEM-BASED LEARNING UNIT: HOW CURRICULUM DEVELOPMENT AFFECTS SCIENCE TEACHERS' UNDERSTANDINGS OF REFORM-BASED PEDAGOGIES

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ABSTRACT:

Problem-based learning (PBL) is a subset of inquiry science teaching that asks students to solve an ill-defined problem through self-regulated learning. This study examined the relationship between teacher understandings and beliefs about inquiry science teaching and development of a problem-based learning curriculum. Through open-ended analysis of interviews with three research subjects, a pre-service teacher, an experienced teacher new to PBL, and an expert teacher experienced with PBL, the study documented changes in teachers' goals for and perceived limitations of PBL In addition to these interviews, two PBL microbiology curriculums were developed for a high school Biology context and subsequently analyzed for alignment with inquiry-science pedagogies. This study contributes to the developing work in creating a practice-based definition of inquiry science teaching.

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INTRODUCTION:

Pennsylvania public schools have only recently included standardized science testing in their Pennsylvania System of School Assessments (PSSA). This inclusion of the sciences emphasizes the increasing importance of science education, especially as the No Child Left Behind act continues to affect school funding. The National Academy of Sciences has also highlighted the need for effective science instruction to "enlarge the pipeline of students who are prepared to enter college and graduate college with a degree in science" (National Academy of Sciences, 2005, p. ES4). The National Research Council has recommended inquiry-based science practice as a as a way to address this need. Therefore, understanding the nature of inquiry-based reforms as they are enacted in real science classrooms is critical to understanding their potential impact on student learning. While teachers recognize that inquiry-based teaching (used interchangeably with reform-based teaching) asks students to draw their own inferences and build evidence-based explanations from experimentation, rather than mere fact-acquisition, most current classroom practice does not represent reform ideas of science teaching. Current documents such as the National Science Education Standards do not adequately characterize what these practices look like in real schools (Abd-El-Khalick, BouJaoude, Duschl, Lederman, Mamlok-Naaman, Hofstein, et al. 2004). Ambiguous definitions lead to teachers' difficulty in enacting reformed-based pedagogical methods in their classrooms (Da-Silva, Mellado, Ruiz, & Porlan, 2006). By increasing their understandings of and ability to develop the different reform-based pedagogical methods in their classrooms, educators could meet the need for better science teaching. This research attempts to characterize the pedagogical knowledge needed for transitioning to reformed teaching through its examination of teacher conceptual changes in content understanding and lesson planning.

Problem-Based learning (PBL), a sub-set of project-based science, is one possible approach to enacting reformed science teaching across a broad spectrum of ages and abilities. Although PBL has been commonly used in Medical Schools since the 1970s, its relation to reform science teaching has created a new emphasis, adapting it to elementary and secondary school enactments (Colley, 2008). Like much reform-based pedagogy, PBL has been defined in many different and sometimes contradicting ways. For PBL to be an effective tool for high school science educators, a clear definition that aligns with the criteria of inquiry-based learning must be articulated. Detailing a successful strategy for PBL curriculum development and implementation is a crucial aspect to widespread incorporation of this pedagogy. Consistent accounts of successful development and implementation of inquiry-based methods can provide guidance for teachers inexperienced in these teaching techniques. Examining how teaching and planning experience can modify these techniques may also help novices from making these same missteps.

Although this single account of a microbiology-based PBL curriculum development and enactment is insufficient to meet the need for greater clarity, as a case it provides initial insight into how planning and teaching a PBL unit can change novice teachers' thinking.

RESEARCH QUESTIONS:

1. How does enacting a problem-based learning curriculum affect experienced teachers' understandings of both problem-based learning and reform-based science pedagogy in general?
    a. How does teaching experience affect what the teachers acknowledge as advantages and limitations of inquiry science and PBL?
    b. Are teachers better able to verbalize a pedagogical theory that reflects reformed-based beliefs following the creation of a PBL unit?
2. How does developing a problem-based learning curriculum and then watching its enactment affect a pre-service teacher's understanding of reform-based pedagogy?
    a. Following an authentic experience in creating curriculum and then observing its enactment in the classroom, are future iterations of that curriculum more closely aligned with reform-based pedagogical theory?

LITERATURE REVIEW:

Research literature useful for informing these questions encompasses several areas: the theoretical framework underlying reform-based pedagogy, the definition of inquiry science, theoretically-grounded structuring of problem-based learning units, and teacher knowledge and beliefs necessary for creating and implementing inquiry-based learning. The literature available around these areas is not always consistent; varying schools of thought exist about the best definition or explanation of key ideas. Empirical research on these topics is even less available, partially due to these contentious definitions and in part because of the relatively recent emergence of PBL techniques in secondary science. Of the available research, discussion focuses on teachers' knowledge of inquiry and orientations to science teaching more generally, not specifically on problem-based learning as an approach to teaching.

Framework of Reform-Based Learning Theories & Pedagogies

Understanding specific reform-based pedagogical practices requires previous knowledge about reform-based views on the nature of science, learning and teaching. Many reformed conceptions assume that all knowledge, learning, and teaching are culturally situated. Although there is a cognitive component involving students' naïve conceptions and conceptual change theory, reformed-educational theorists propose that all knowledge is specific to the social context that generated it (Lave & Wenger, 1991). Individuals only learn when engaged in a community of practice wherein the knowledge is applicable; knowledge cannot exist as an abstracted entity outside of the context in which it is generated. By positioning science knowledge as the product of social interactions, the traditional, empirical view of objective science theories grounded in concrete observations is called into question (Da Silva *et al.,* 2006). Instead, teachers and students both must embrace the tentative nature of science and that "in the observation of reality, it is impossible to avoid a certain degree of distortion induced by the observer" (Da Silva *et al.,* 2006, p. 462). Clearly, a view that all science is socially situated is drastically different than the absolute view about objectivity and truth. The emphasis on the social context of learning has focused recent educational research on the socio-cultural aspects of the classroom. For example, "argumentation discourse" is a more specific reform-based classroom practice that developed from the situated nature of science and knowledge-generation. As theoretical views of learning as socially situated create classroom practices like argumentation discourse, so these practices generate specific pedagogies like problem-based learning.

For the purposes of this study, reform-based pedagogy is best defined by those framing it in terms of argumentation discourse. Richard Duschl (2006), states in his work, *Supporting and Promoting Argumentation Discourse in Science Education*, that reformed pedagogies acknowledge the importance of both student-centered active learning and students' prior knowledge about the topic (Duschl & Osborne, 2002). However, the most critical aspect to reform-based practices is that "the focus of students' work should transcend the declarative to include procedural and strategic knowledge…enable students' abilities to reason and reflect metacognitively on their own learning and the construction and evaluation of scientific knowledge" (Duschl & Osborne, 2002, p. 45). This quote exemplifies the terminology-laden nature of current science education research, but also describes the desired outcomes of student learning as being focused on an ability to process and evaluate information. A traditional pedagogical strategy would view students as a *tabula rasa* and emphasize a transmission model of learning and teaching (Da Silva *et. al 2006)*. When perceived through the lens of argumentation discourse, science teaching focuses on "promoting reasoning skills, 'doing' science, or learning *about* science" (Duschl & Osborne, 2002, p. 51). Effective teaching scaffolds students' abilities to create and evaluate argumentative positions relating to the subject topic and develops a more rigorous understanding of how scientific knowledge is constructed within a social consensus. While often mischaracterized as students' "discovery learning," these reformed-based practices can still offer structured objectives and methods for developing scientific inquiry into the subject phenomena. "From this point of view, inquiry draws upon and situationally applies social knowledge and is not merely an individual process of learning through hands-on activities" (McDonald & Kelly, 2007, p. 166). Although the terminology varies slightly from author to author, reform-based pedagogy can be characterized as acknowledging the socially situated nature of science as well as students' preconceptions, creating student-centered communities of learning, and emphasizing the application of scientific knowledge to strategic and procedural problems.

Problem-based Learning as defined within Inquiry-Science

Problem-based learning was developed in the 1970's in response to medical school students' inability to apply their classroom and laboratory knowledge in clinical stiuations. Medical school instructors attempted to counter this problem by dividing the students into small groups that were then assigned collaborative clinical case studies. These studies not only required the practical application of students' previously acquired knowledge, they also necessitated that group members were self-motivated enough to seek out novel information in order to progress in their diagnosis (Colley, 2008). PBL has been experiencing a renewed interest among elementary and secondary level educators because of its collaborative nature and its ability to develop students' self-regulating traits (Chin & Chia, 2008).

Although not intentionally developed to fit this theoretical framework, the emphasis on collaboration and self-regulation in PBL easily combine with the objectives of argumentative discourse and are potentially a concrete strategy for implementing an inquiry-based method. While promoting a collaborative effort to diagnosis a patient or investigate another problem, students are engaging one another in argumentation discourse as they seek to defend and evaluate potential solutions. The teacher takes a backseat role as a facilitator in helping the students develop good evaluative criteria but is perceived as more of an equal than as a disseminator of knowledge (Duschl & Osborne, 2002). Because students are responsible for identifying what constitutes a good argument within their group, they gain a firsthand understanding of how similar decisions would be made in actual scientific research. Also similar to authentic science practices, PBL promotes intrinsic motivation and self-regulated learning. By having students take ownership of a realistic scenario-problem, PBL fosters intrinsic motivation and interest in a practical application of science knowledge. Participants in PBL also develop self-regulated learning skills because each group member must identify "what they know, what they want to know, and how to find that information" (Hmelo-Silver, 2004, p. 240). Problem-based learning fulfills the requirements proposed by a discourse framework (student-centered, requiring evaluation of information, promoting reasoning skills) to qualify as inquiry-based pedagogy.

Structuring a Problem-Based Learning Activity

The most critical task in designing a problem-based unit is the selection of an ill-defined problem. The teacher can either specifically select this question, or students can be allowed to create their own research question to investigate a broader, teacher-selected topic (Chin & Chia, 2005). To constitute an ill-defined, or ill-structured, problem, the assigned task should not provide the students with a clear-cut correct answer. Instead, students must generate multiple possible solutions and then justify why the solution that they selected was the best or most accurate (Hmelo-Silver, 2004). The first ill-structured problem created for the PBL does not provide all of the needed information for the solution; students must identify needed information and be willing to adapt as the situation changes. By using an ill-structured problem with multiple potential solutions, students are required to engage one another in argumentation and thereby shift the classroom emphasis from a teacher-centered strategy to a student-centered pedagogy (Gallagher, Stepien, Sher, & Workman, 1995).

It is also important that the ill-structured problem is relevant and applicable to the students' lives and interests. By selecting a problem that is structured within a larger task context and has familiar goals for the students, teachers will foster interest in the project and overall scientific competence (Duschl & Osborne, 2002). After selection of a question, providing sufficient scaffolding for student achievement is the next largest task. Research from the NSTA has found that younger students are capable of completing PBL tasks provided they have adequate scaffolding (Hmelo-Silver, 2004). As students become more familiar with PBL curriculum, they will become better self-regulated learners, and thus better able to learn from PBL experiences (Hmelo-Silver, 2004). Prior to this self-regulated stage, teachers can aid in student achievement by providing explicit criteria for academic success. Teachers can also provide intermediate scaffolding in the form of worksheets or journals that help direct students' organization of information and knowledge gaps.

Teacher Knowledge and Beliefs Needed for Problem-Based Learning

A diverse field, research in teacher beliefs investigates many different aspects of inquiry science pedagogy. Studies that specifically examined how educators viewed and enacted inquiry science were selected as additional comparison populations to the interview subjects. Similarly diverse, the studies about teacher knowledge were selected specifically for their pertinence to inquiry pedagogy and high school microbiology. Finally, some necessary assumptions were made in regards to other forms of teacher knowledge when examining the specific needs of teachers enacting the curriculums produced from this study.

Within the teacher knowledge studies, many focused on why many science teachers neglect inquiry practices within their classrooms. Zion's (2007) qualitative study on Israeli teachers' implementation of an open-inquiry biology curriculum found that some teachers had difficulty with experimental planning in regards to collecting valid evidence. This inability to cite and defend evidence decreased the teachers' capability to employ argumentation discourse frameworks in the classroom (Zion *et al*., 2007). Zion (2007) also discussed how teachers' lack of scientific knowledge impacted their willingness to fully engage in an inquiry activity (Zion, Cohen, & Amir, 2007). It found that teachers must have extensive subject-matter knowledge in order to be comfortable with student-selected topics within the umbrella topic.

In addition to a lack of teacher subject-matter knowledge, inquiry literature also identifies purely pedagogical factors like time, class size, and student motivation as issues that prevent the implementation of reform-based practices (Da-Silva, *et al*., 2006; Brown, Abell, Demir, & Schmidt, 2006). To counter these challenges, certain pedagogical knowledge played an important role in the enactment of this unit, as it does in every classroom lesson. Because the most problem-based units are based in small groups, the teacher needed to demonstrate an ability to place students in functioning and balanced groups that would be able and motivated to, communicate inter and intra-group. Related to the small-group set-up, teachers needed to maintain students' on task behavior as well as mediate the group conflicts and distractions that would invariably arise. In addition, an ability to frame the activities so that students could both perceive the final output, and place the smaller lesson within the greater problem's context was an important skill.

The last in the triad of teacher knowledge, the pedagogical content knowledge required to enact any problem-based learning experience can be divided into 5 sub-categories. According to Goodnough & Hung (2008), a teacher would first require an understanding of the varied science teaching orientations and possess a science teaching orientation that is compatible with inquiry-science (1). In addition, teachers must be able to recognize how different components of the science curriculum interact and support one another (2). As students' develop specific knowledge in a focused area, teachers must build connections to topics more directly relevant to high school curricula. It also required knowledge of outside disciplines' curricula and how to integrate those concepts into the larger problem and information set. To create a discourse-rich PBL unit, a teacher needed not only recognize content misconceptions, but also student misunderstandings about creating valid evidence and logical arguments (3). Also, problem-based learning challenges teachers' knowledge of both traditional and alternative assessments (4). This difficulty was especially true in large class sizes where it was difficult to formally grade every justification and piece of evidence. Finally, knowledge of instructional strategies, specifically in fostering discourse and scaffolding students persuasive and dialectic skills (5), was a critical component of PBL teachers' PCK (Goodnough & Hung, 2008).

Finally, in addition to the three types of knowledge typically associated with science teaching, the problem-based learning unit designed through this study required knowledge of the local community. Professionals were asked to evaluate student presentations in order to provide a measure of authenticity to the students' work and also to act as motivation by bringing in outside evaluation. Teacher knowledge of the community was also important for connecting the more global diseases to students' everyday life. While there was not always an obvious means of exposure for the students to some of the selected diseases, relating these diseases, as well as the more prevalent ones, to the students' everyday experiences increased motivation and engagement. To accomplish this goal in a relatively affluent and sheltered community, the teacher needed to draw on his knowledge of community events. Atypical travel experiences (i.e. student exchange programs, missionary trips, general travel) of some students acted as the plausible method of exposure. If the teacher had been unaware of these trips, he would not be able to make the connection between disease and student.

Accompanying teacher knowledge, teacher beliefs and views about inquiry-based pedagogy play an important role in a successful development and enactment of PBL curricula. Related to the work on barriers to inquiry, Da Silva's (2006) retro- and introspective case study examined how her changing conceptions about the nature of science over a nine-year period impacted her perspectives on science learning and teaching. Initially, Da Silva identified herself as a traditionally oriented teacher, yet over the study period her conceptions developed into reform-based ideas. As a novice teacher, Da Silva subscribed to a general scientific teaching method with practical applications centered on a comprehensive textbook. Nine years later, her teaching practices reflected a much more complex understanding that integrated students' evaluation of ideas with multiple sources of scientific authority and classroom improvisation. Da Silva also noted that with experience she began to emphasize the importance of students' procedural knowledge (Da Silva *et al.,* 2006). In addition to the insight about the evolution of science teachers' ideas on teaching and learning, this study employed a novel method of data collection, including personal experiences and conceptions as a significant portion of her study data.

Brown (2006) and Crawford (2007) both interviewed teachers about their views on classroom inquiry; however, they looked at very different populations. While Brown conducted an experiment with university professors, Crawford examined how pre-service teachers, like myself, understood and enacted of inquiry science in their classroom. As predicted by the authors, the mentor teacher's support of new and reform-based pedagogies was an important factor in the student teachers' classroom practices. Student teachers that had traditional or unsupportive mentor teachers were less likely to enact inquiry-based teaching methods, and were more likely to express concerns or doubt about inquiry teaching's efficacy and their abilities to implement a reform-based pedagogy.

Surprisingly though, the authors found that the student teachers' complex values and beliefs about science and science teaching had a greater impact than mentor support. It suggests that even if teacher education programs adequately prepare novice teachers in how to enact inquiry-methods, they might never be put these methods into classroom practice (Crawford, 2006).

According to Crawford, teachers must believe that these methods are worthwhile and congruent with their values about science teaching in order to implement them in the classroom. Brown (2006) indicated that university professors believed inquiry investigations were worthwhile for the development of problem-solving skills in their undergraduate students, but required excessive resources and time. These professors valued inquiry labs that asked students to generate their own research questions and protocols more than "cookbook" labs; however, they thought that this type of activity was only suitable for higher-level students.

While the majority of the selected studies focused on *what* the teachers perceived as inquiry or *who* they thought was capable of inquiry studies, only one small qualitative study mentioned differences in *how* teachers identified inquiry teaching. This study identified differences based on levels of teacher experience. McDonald (2008) noted that when comparing experienced to pre-service teachers, several differences emerged. Experienced teachers were much more selective about what constituted inquiry lessons and were able to indicate that the planned lesson may have intended to be inquiry-based but failed in its enactment. Pre-service teachers failed to make this differentiation between planned and enacted inquiry. Experienced teachers were also able to adopt a multiple-lesson perspective of classroom activity and inquiry whereas pre-service teachers tended to focus on individual student-teacher interactions (a disparity known as "grain-size") (McDonald, 2008).

The literature available to pre-service and practicing teachers about what inquiry practices are, and how to enact such practices, is limited. By outlining how several teachers at differing career stages identified inquiry practices in their own classrooms, this study endeavored to contribute to this need for more explicit information.

METHODS:

Data Sources:

Multiple data sources were utilized in addressing the research questions:

- How does enacting a problem-based learning curriculum affect experienced teachers' understandings of both problem-based learning and reform-based science pedagogy in general?
    - How does teaching experience affect what the teachers acknowledge as advantages and limitations of inquiry science and PBL?
    - Are teachers better able to verbalize a pedagogical theory that reflects reformed-based beliefs following the creation of a PBL unit?
- How does developing a problem-based learning curriculum and then watching its enactment affect a pre-service teacher's understanding of reform-based pedagogy?
    - Following an authentic experience in creating curriculum and then observing its enactment in the classroom, do future iterations of that curriculum more closely aligned with reform-based pedagogical theory?

To answer the first research question, interviews were conducted with two high school Biology teachers. The first Biology teacher, "John", my primary collaborator in the PBL curriculum development, was interviewed twice, for a total of 25 minutes and 8 pages of transcribed data. The first interview occurred in February 2009, while John and researcher were co-developing the curriculum for a problem-based learning unit on microbiology. The second interview occurred in April 2009 following the development and partial enactment of the same microbiology unit. The second Biology teacher, "Bill", was used for comparison against the main teacher and the researcher-participant and was interviewed for 25 minutes in March 2009. The transcript produced by this interview was 5 pages in length. For the original interview questions, see Appendix A.

Development in the pre-service teacher's (my own) understanding was determined through analysis of the research journal and through comparison of two microbiology-based PBL curriculum. The first curriculum was developed in conjunction with John in February and March of 2009. The second, revised curriculum was created in April of 2009, following John's and my observations of the first curriculum's enactment.

The table below places the collection of the multiple data sources into chronological order.

Date	Event	Data
February-May 2009	Documentation of project process in pre-service teacher/researcher's research journal	Excerpts of research notes and journal entries
February 2009	Pre-development interview with John	Ten minute interview; 3 pages transcribed
February-March 2009	Creation of original PBL unit through collaboration between John and pre-service teacher/researcher	Outline of high school microbiology-based PBL unit
March 2009	Interview with Bill	25 minute interview; 5 pages transcribed
Early April	Enactment of original PBL unit	
April 2009	Post-enactment interview with John	15 minute interview; 5 pages transcribed
April 2009	Creation of Revised PBL Unit by pre-service teacher/researcher	Outline of high school PBL unit in Microbiology
October 2009	Enactment of Revised PBL Unit	No data collected

Context of Data Collection:

Through my collaboration with John, a high school Biology teacher, I focused on how his understandings and expectations of problem-based learning changed with the development of the seminal PBL unit. As a co-developer of this unit, I also examined how a practice-grounded activity changed my understandings of PBL pedagogy, specifically how to develop and write my own PBL unit. To contrast with our emerging understandings of PBL, I also spoke with Bill, a Biology teacher who had identified himself as an experienced educator in this pedagogical approach. Both of the practicing teachers were male, Caucasian, secondary education Biology teachers situated within primarily Caucasian school districts. The site of my collaborative curriculum development with John was a school classified by the National Center for Education Statistics as situated within a small city and has roughly 10% of students receiving a free- or reduced-price lunch. John, my collaborator and main research participant had been teaching 10th grade Biology for over ten years and was a well-established presence in the school community. Bill, the teacher interviewed for the purposes of triangulation was located at a school that was situated within a large suburb and has a free- or reduced price lunch rate of less than 2% (U.S. Dept of Ed., 2008). Bill was considered an expert Biology teacher in his 40th year of teaching at the time of interview and was a similarly well-established member of both the school and local community. As the only non-practicing teacher, I still had strong connections with both school settings. I had been a student of Bill's science classroom 5 years earlier, and had been a University-level student in John's school's community for the past 4 years.

In my initial meeting with John, he offered several Biology units typically taught during the spring term as candidates for revision into problem-based learning units. I selected a topic that, while often overlooked in a traditional Biology classroom, I anticipated would be well suited as a focus for the development of a problem-based learning unit. Microbiology is often taught with several definition-rich lectures that touch on topics of drug resistance, evolution, and epidemiology, but rarely go beyond virus and bacteria structure and function. Given PBL's origin in medical schools, creating a medicine-based microbiology unit that emphasized diagnosing an infectious disease seemed both engaging for the students and useful context for developing their understandings in Biology. Over the course of 10 class periods, the students were asked to diagnose a "mystery disease" after being given the faux-medical records of an individual patient.

Analysis:

The first set of data from this study was open-coded using qualitative discourse analysis to compare John, the focus teacher's pre- and post- development descriptions of PBL and inquiry-based teaching with those of the pre-service teacher (myself) and experienced teacher (Bill)(Huberman & Miles, 1994). Analysis was focused on the content of the teachers' inquiry conceptions, but also on their ability to communicate personal teaching theories: the clarity and specificity of their explanations and their accuracy in using the reform-teaching terminology. The coding system was intended to generate specific classroom applications for PBL by emphasizing teachers' pedagogical growth through development of an inquiry-based unit. The second research question was answered with a comparison of the initial microbiology unit to a later curriculum designed for implementation in a 12th grade Biology Elective course. This comparison and subsequent analysis highlighted how aspects of the new curriculum matched expert definitions of problem-based learning and inquiry-pedagogy. In both instances, comparison was based on the curriculum plan and not actual enactment in order to eliminate the variable of the teachers. Through identification of alignment between unit plan and theoretical definitions via open coding, progress in my understanding was documented (Huberman & Miles, 1994).

RESULTS:

Data is presented in three forms: brief profiles of the three study subjects, comparisons between the original microbiology curriculum and its second iteration, and generalized themes with supporting excerpts. For the original interview questions, curriculum, and revised unit plan, see the attached appendices.

Profile 1: Bill, the PBL-experienced teacher

As noted earlier, Bill was an extremely experienced science teacher working in an upper-middle class, suburban school district. After 40 years of teaching, he was assigned mostly AP Biology and Honors Biology II classes, although for the first time in over a decade he also had a class of honors freshman Biology. He described his teaching style as:

> "I use lab experiences to set a framework for students learning, conceptual work, the theory base where it has to come from the students. So a lot of it, a lot of the conceptual work, takes place, or ideally takes place, outside the classroom, outside the laboratory, where highly motivated students do reading... the day-to-day organization is around lab experiences that connect to contextual, theoretical, material that are accessed outside the classroom. And then ideally integrated."

His interview was confident as he described two new PBL projects that he had enacted or was in the process of enacting. Bill voiced clear opinions about his conceptions of inquiry and problem-based learning and explained the terms as such:

> "Well, inquiry-based is you can't know the answer before you start… The other part of the inquiry is design the protocol yourself. So if you look it up in a lab book, it's a recipe; it's a cookbook; you're cooking; you're a technician; you're not a scientist. So

we try to get away from that whenever possible. When we do a protocol and we're following it, there are always ways to diverge."

"It's not just studying a topic for the sake of studying it. It's based around solving problems…The problem-based part [of inquiry] is that you have a problem you're interested in. Not a problem that someone assigned to you but something that you want to solve."

Profile 2: Myself, the pre-service teacher/researcher

At the onset of this study, I was in the process of completing a Masters in Education degree program and had completed my pre-student teaching practical in addition to numerous less-formal teaching experiences. I had recently completed the coursework to receive my Bachelor's of Science in Biology, although my degree had not yet been conferred. The October 2009 enactment of the second PBL curriculum occurred during my semester-long, student-teaching practicum. As both a researcher and a participant in this study, I had to more vigorously attempt to develop my understandings of inquiry and PBL science. Having very limited classroom experience, my writings were marked with apprehension and some confusion about the theory-to-practice translation. I mentioned that "it all seems to run together and I can not seem to keep all the names straight." My original curriculum development relied heavily on the advice of my co-teachers and peers and incorporated many aspects of John's traditional microbiology unit. Initially, my writings reflected this naïve nervousness as well as my uncertainty about the success of my curriculum. Later, my writings adopted a confident tone as I became more familiar with the unit although I continued to question the problem-based learning units' effectiveness at teaching microbiology. While I recorded that "things seem to be coming together with my ideas and the materials from Jack," I also wrote "the kids seems to be enjoying the activity but it's hard to tell if they are learning about bacteria structure or just how to use WebMd." My second PBL unit, designed without the constraints of a pre-existing classroom, similarly reflected a more confident tone although also expressed concerns about effectiveness.

Profile 3: John, the focus teacher

Also noted earlier, John works in a similar school district to Bill, although he had less teaching experience and slightly more diversity within his school. He also was assigned younger and lower-tracked classes. The majority of these classes were academic-level sophomore year Biology, with one or two sections of introductory Honors Biology. Lacking Bill's experience, John provided more ambiguous, less practice-grounded, definitions of inquiry and PBL in both his pre- and post-development interviews.

> "[Referring to PBL and project-based learning] I was reading something about trying to differentiate the two things and I was kind of getting it but at the same time, you know, it's still a lot of theory and philosophy about how to teach."
>
> "It's [PBL] still so new to me right now that I don't think, I'm not sure what to do differently at this point [when asked if his ideas about PBL design had changed].

Curriculum Comparison:

Both microbiology problem-based learning curriculums were designed to use 10 class days for group work, activities, and lectures and use one additional day for group presentations to the class. They both used mock-medical records to create case studies of infectious disease patients that were solved by groups of four students. These students used the provided information, as well as Biology text and Internet sources, to diagnose their patient and students were also required to solicit more specific information from the “hospital” by completing summative assessment forms. The first curriculum, designed with John for his classroom (Curriculum A), assigned each student group to one diagnostic case study that contained a patient with bacterial infection (students did not know before the conclusion that all of the diseases were caused by bacteria). Designed after watching Curriculum A’s enactment and in the context of a senior-level elective Biology course, the second curriculum (B) assigned student groups to two case studies, one of which had a bacterial pathogen and the other which was the result of a viral pathogen. While no students in a Curriculum A classroom would have the same pathogen, students in Curriculum B would unknowingly have ‘patients’ with the same disease, although these case studies would differ in minor information about patient names and vitals, etc. Curriculum A and Curriculum B shared many of the same core conceptions and structures in their initial planning phase.

The earlier curriculum (Curriculum A), which was designed for younger students, included one traditional laboratory exercise of culturing bacteria and molds found in common areas of the school. It also had fewer days devoted purely to group work in the diagnostic case study (2 compared to 5). This difference in days was balanced by Curriculum A’s 4 days of lecture to which is contrasted with Curriculum B where much of this information was integrated into classroom discussion. Neither PBL units emphasized traditional laboratory exercises although they both included a variety of inquiry-activities. As noted, Curriculum A included a “Swab the School” activity where students cultured their own bacteria from the school site, and also included a “Microbial zoo” so that students could observe an assortment of bacterial structures. Curriculum B did not incorporate any traditional hands-on activities to teach practical microbiology skills; however, it did include an epidemiology game where students were required to determine Patient 0 in the community. The summative assessments for the two curricula were also significantly different: Curriculum A required students to present their diagnosis and other basic information about their pathogen to the class via a PowerPoint presentation; Curriculum B asked students to select one aspect of their diagnosis that they found interesting and to research that topic further. The results of these group studies were shared in a poster presentation session that multiple class sections attended.

Although they were similar in the core design (a medical mystery), Curriculum B pedagogically differed significantly from Curriculum A in that B placed a greater emphasis on group discussion (both small group and whole-class) and had a more open-ended assessment. Content-wise, Curriculum A included a more traditional hands-on exercise of culturing mold and bacteria found on common surfaces; its content was distinct from the previous and following units in the class. Curriculum B asked students to identify both viral and bacterial diseases in the case-study portion and selected diseases that had a clear connection to evolution. The pedagogical differences are significant because they require very different skill sets in the teacher; in Curriculum B, the teacher must be more comfortable with the material in order to successfully guide the discussions so that they address the needed information. The Curriculum B teacher must also determine a fair way to evaluate the summative assessments as they can cover a wide range of topics, many of which may be outside her content-knowledge. The informational content-differences are significant in that they demonstrate the placement of the case-study activity within a larger curriculum context. Instead viewing the medical mystery as a fun but isolated activity, Curriculum B structures the unit so that the knowledge of diseases will lead to a deeper understanding of evolution. Overall, Curriculum B's initial design implicates a better understanding of the subject matter and how it could be used to teach multiple biological concepts.

Emergent Themes:

From the collected data, four themes relating to teacher knowledge, beliefs, and growth about problem-based learning developed. The responses pertaining to these four themes differed between interview subjects. These four themes were further organized into two categories: what the interviewees talked about, and how they talked about it. The first three themes reflect the content of the research subjects' answers and conceptions. In addition, data from the curriculum comparison was then integrated into these four themes when appropriate.

Theme 1:Goals for Students

Both practicing teachers identified non-science skills for their students as one of their primary reasons for adopting an inquiry-based approach although these specific skills varied in each interview. At the initial interview, John stated that "kids just don't think for themselves anymore…and it's being able to correct that that we [teachers] don't know very well. I think that PBL will help that out. I really hope so." Post-development, he cited being able to work in groups as one of the important goals of PBL enactment. Bill's response to the importance of inquiry teaching more closely aligned with John's initial conception; however he was much more specific about his long term goals.

> "So that the long-term goals are that I want students to learn about learning. I want them to be excited about science. I want them to be good consumers of information

whether it's science information or any information. I want them to be able to write and communicate effectively."

My own writings seemed initially more concerned about meeting the students' basic immediate needs than effective inquiry teaching and lacked a personal perspective about student objectives. I worried about the information presented and when and how to collect data more frequently than whether or not the unit was a fair representation of PBL or the long range implications of how or what my students learned. My writings referenced "vocabulary lists," "lab exercises," and "how to grade students," and never mentioned long-range goals. In my second iteration, I was much focused on creating a unit that emphasized inter and intra group discourse. Although I still did not have a personalized view of the students (having them "think for themselves," or be "consumers of information"), I was focused on students selecting a topic that was personally interesting to them and deeply engaging in researching that topic.

The compared curricula also emphasize different student outcomes in their design. Curriculum A adheres to information specific to a traditional microbiology unit and focuses topics like bacterial and viral morphologies. The use of diagnostic case studies is to engage students in the material and to help make the information more relevant. All of the selected diseases could be potentially found in the school community and students are asked to justify how someone in their peer group could become infected. Curriculum B has less clear content objectives for its students and has a different focus in its selection of pathogens, all of which are associated with drug-resistance. In addition to being a possible transition point to an evolution unit, this theme helped direct students to epidemiological studies and societal issues relating to these diseases.

Theme 2: Limitations of PBL

Over the course of development there was a trend from being concerned about student interest affecting student learning to a more varied perspective about what would limit learning. John had noted his greatest concerns as being able to "think though all the details in minutiae," and that the students would not take the lesson seriously. "There will be kids that just do not care, and there will be problems, not major ones, with that." Echoing these concerns, my research journal from this pre-development period cited lack of student interest as a major concern. "I really hope that we can do the House study because I think that just public health is boring; how are we going to occupy them," I wrote.

Post development, I found that both John and I had identified different aspects of PBL as limiting, aspects that coordinated with Bill's interview. When asked if he had sacrificed anything for his newly PBL classroom, John responded, "Time…I could have taught this unit in three or four days…instead it's taking two weeks." He also commented on the intensity and breadth of teacher effort required to get the project moving. I also identified teacher preparation time as a problem in my research journal, stating, "This whole thing is so much more immense than I had anticipated, I feel less than a step ahead of the students in preparing their materials." Bill similarly identified teacher preparation as the limiting factor in enactments of PBL activities. "It's very difficult to get teachers away from their tried-and-true curricula that they're comfortable with. First off, it's a hell of a lot more work; it has to be designed from scratch."

Another limitation of PBL that the practicing teachers attended to was assessment. While John expressed concern for both himself and his students about being unsure of assessment, Bill attributed PBL-associated problems of assessment exclusively to students. Stated John:

> "And so I think the kids are a little unsure, really more than a little unsure, of how the grading process works, cause when it comes down to it they want to know what their grade is going to be. And obviously, when I'm not sure, they're not sure. I think that's one of the weaknesses right now, for me anyways."

Bill similarly noted younger students' difficulty in dealing with alternative assessments:

> "They can get confused. This is true of the younger kids, the honors Bio class I have this year. They're just used to their work being in little 2 or 3 days chunks. And it's a big two week chunk with an ending date that is kind of nebulous. That's difficult for them to deal with and so it creates a little anxiety. The question is not "how are we going to be assessed," but more "when's the test?" Well there might not be a test; there might be something other than a test… "Well when's it due and how many points is it?" "

Following development of his seminal PBL unit, John began to perceive PBL limitations in a manner similar to other, experienced teachers. These identified limitations were associated to education structures like class time, teacher preparation time, and assessment. Prior to development, he emphasized his concerns about problems that they students might have with engaging in the lesson.

Theme 3: Lesson Structure and Breadth

John, in his initial interview, emphatically stated the importance of project development before class enactment. "Development is just thinking through all the details in minutiae before you get to the classroom. I have it all pretty much worked out when I get there." Although he later altered this statement by saying that he did his planning "last minute," and clarified his statement of minutiae to mean a rough, unit-long plan of "what we're going to do day-to-day, it is a great starting point," John's idea of lesson structure in a PBL unit differed greatly from Bill's. Frequently, Bill referred to having no day-to-day guide of student activity and present his PBL lessons as much more student directed. He dismissed scenario-based PBL units as fake, stating

"And so the problem-based is I think, have a real world problem, develop a protocol and make it interdisciplinary and I guess incorporate it. And let it go where it goes. If you have a so-called problem based unit and its completely choreographed and controlled by the teacher then it's just another fake scenario. And to me if I were a student, that wouldn't be interesting to me if someone was controlling all parameters of the work."

In addition to the obvious contrast between John and Bill's opinions on lesson structure, opposing ideas also emerged about the role of other disciplinary knowledge in a PBL unit. John identified that the "next step" of his unit would be to incorporate more information from other science units and try to condense more generalized Biology into his specific Microbiology unit. He acknowledged that bringing in other English or Social Studies teachers for a "team project" was "do-able," but wanted to focus on scientific content. Bill identified the next step of his PBL unit, which focused on corn, as "getting into farm policy and economics. The next step would be to get an econ teacher, to get someone from a historical perspective, a history teacher that would be able to make it truly multi-disciplinary."

Curriculum A more closely followed John's ideals of lesson planning, which was logical given his role as the teacher. It is very structured and uses multiple lecture-lessons to ensure that students are exposed to all of the main topics of the unit. The diagnostic case studies are distributed throughout the entire unit and students' summative assessment is based on their successful solution to the problem designed by their instructor. Curriculum B incorporates more aspects of Bill's perspective in its deviations from Curriculum A. Although the simulated-case study is still a central theme, students have a greater freedom for independent research and increased multi-disciplinary crossovers. From this emergent theme, a range of conceptions about lesson planning and inclusion of other material was demonstrated. No consensus emerged about what was ideal for student learning

Theme 4: Clarity

The fourth emergent theme of clarity begins to examine how the subject teachers and I spoke about problem-based learning and dealt with the terminology-laden nature of science-education reform. Although Bill's ideas did not always match with literature-definitions of certain terms, his responses were the most direct and concise. Specifically his assertion that at the most simplistic level, "inquiry-based is you can't know the answer before you start…the other part is design the protocol yourself." This definition neglected to address any components of argumentation or justification of students' explanations. He also used two concrete examples of his own practices in his explanations to elucidate the differences that he perceived between inquiry and PBL that helped to demonstrate his implicit conceptions of teaching and learning.

John's ability to navigate the vocabulary of reform-pedagogies noticeably increased over the 2 months of collaboration. He initially "was not sure how to characterize my teaching styles," and that "it's all educational jargon." Post-development, he evidenced more confidence in describing his classroom and his students' behavior than earlier. Over the course of the Curriculum A development process, I did not note any changes in the clarity of my writing. My research journal entries tended to be verbose and rely heavily on education jargon to explain poorly defined terms. However, there is a discernable difference between Curriculum A and Curriculum B's specificity and clarity. Curriculum B identifies driving questions for every lesson and suggestions for how the teacher should guide classroom discussions to promote progressive discourse. Overall, with first-hand experience in reform-based curriculum development, teachers seemed to be more comfortable and confident in expressing their conceptions of inquiry and PBL. However, for the pre-service with a strong theoretical background but little classroom experience, the development process did not improve her ability to verbally link theoretical concepts to actual classroom practice.

To summarize these four themes across the different data sources, the following chart was constructed.

Data Source	Theme 1: Goals for students	Theme 2: Limitations of PBL	Theme 3: Lesson Structure and Breadth	Theme 4: Clarity
Bill	For students to be "good consumers of information"	Time, creating a fair assessment of student work, adequately structuring students for long-range assessments	No "day-to-day" plan of lesson structure, heavy emphasis on inclusion of other disciplines	Clear definitions and strong wording, two concrete examples
John	Prior: For students to think independently Post: For students to work well in groups	Prior: Lack of student engagement Post: Effective means of student assessment, time	Focused on having a whole unit plan with some description of each day's activity. Considered interdisciplinary work "do-able" but difficult	Increased clarity and confidence in writing
Me	Prior: For students to learn the material Post: For students to research a personally interesting topic	Time and energy intensive teacher-planning required	NA	Heavy-use of jargon, few connections to practice-based definitions
Curriculum A	For students to learn microbiology content-knowledge	NA	High structure, little to no potential for non-science disciplines	Unclear connections between curriculum and inquiry teaching
Curriculum B	For students to learn about microbiology and be exposed to epidemiology, study a personally interesting topic	NA	High structure, large potential to include outside disciplines depending on student-selected topics	Driving questions for each lesson, suggestions for teachers to increase argumentation discourse

DISCUSSION:

Comparison of the emergent themes with previous research yielded both corroborative findings and differences, both with implications. Some of these findings are also seen in the curriculum comparison data.

Unlike in Da Silva et al.'s (2006) study, where the subject demonstrates significant changes in her understanding of science teaching, learning and the nature of science from her experiences, the experience of the PBL unit development did not produce the same changes. Although the emergent themes identified some differences in John's perceptions about inquiry pre and post-development, his overall conceptions of inquiry-science teaching and the nature of science did not radically change. Likewise, myself as the pre-service teacher, while gaining a greater appreciation of grain-size, did not dramatically improve her ability to connect practical applications to teaching theory. A great deal of this difference is attributed the length and intensity of the experiences between pre- and post assessments; however, the need for multiple PBL and inquiry-based experiences is significant in itself.

Perhaps because he typically teaches only high school juniors and seniors, Bill's views on classroom inquiry mirrored Brown et al.'s (2006) findings of those same views held by college teachers. Both identified groups stressed the importance of students developing their own research questions and protocols and concerns about implementing inquiry activities in younger groups. However they differed in their long-term goals for students beyond scientific fields. While Bill identified "being a consumer of knowledge," as an important goal of his inquiry-based teaching method, college science instructors did not believe that inquiry-based lessons were appropriate for non-science majors.

Examining the five emergent themes provides some insight into how a range of expert to novice teachers approach incorporating reform-based pedagogies into their classroom. They also demonstrate that each participant had some weaknesses yet also comparative strengths in their understandings of inquiry-science and problem-based learning. Bill's concise definitions and heavy use of classroom examples demonstrated how he has used inquiry-methods to support his long-term goals for his students and increase engagement and practical applications in the classroom. However, his explanations of his teaching practices neglected developing argumentation and justification skills in students, indicating that although robust, his understanding of inquiry was incomplete. In his interviews, John's understandings of Inquiry and PBL were much less practice-grounded than Bill's, yet over the course of the development process, John became more confident in enacting reformed pedagogies. He also emphasized the importance of group work in successful PBL units, an aspect that Bill did not acknowledge. Myself as the pre-service teacher had hoped that more experience in an initial authentic curriculum development would increase my ability to provide practical examples of commonly used educational buzzwords. Through collaboration on PBL development, I was better able to identify inquiry through a change in grain-size perspective, but was still unable to avoid jargon-filled language when explaining reformed pedagogies. However, my theoretical knowledge about inquiry-science and problem-based learning was the most closely aligned with educational researchers.

Although I was disappointed by my growth across the development of Curriculum A, a critical analysis of Curriculum B demonstrates a more robust understanding of inquiry pedagogy that more closely corroborates research, following my observations of

Curriculum A's enactment. This analysis highlights three ways that the second iteration more closely follows the education researchers perspective of inquiry-science teaching and specifically problem-based learning.

I. Selection of an Ill-Defined Problem in Curriculum B:

As the most important part of a problem-based learning unit, selecting an appropriate ill-defined problem was a critical task for both curriculums. Both instances were more teacher-centered PBL experiences that did not allow students to generate their own investigation and so it was important to pick an ill-defined problem that was interesting to a broad range of students. With the prevalence of medical dramas in the media (Grey's Anatomy, ER, House, etc.), students were familiar with medical diagnosis mysteries, and many aspired to be physicians. In addition, by placing students into the role of doctors treating patients, feedback was readily available in the form of response to treatments, new symptoms, and mortality. As students must commit to researching a solution for the problem and remain engaged in the experience, the task was realistic and had multiple opportunities for clear feedback about the students' success (Hmelo-Silver, 2004). While both curricula addressed a significant science concept (microbiology), the second iteration was better in that it provided a clearer transition into evolution with multi-disciplinary facets for the students to explore (Gallagher et al., 1995). In addition, the second curriculum selected infectious diseases with important roles in epidemiology and evolution, leading to interesting implications about global health and medical ethics, and in some cases exploring a rich historical background. Along with complexity and interdisciplinary attributes, the selected problem was relevant to the students' experiences and engaging.

II. Small and Large Group Discussion Format

While this unit plan admittedly lacked laboratory activities, the discussion-rich format was justified through both the general argumentation discourse framework and Woodruff and Meyer's (1997) research in intra- and inter-group discourse. Their work studied discourse patterns among professional scientists both within the same lab group and between competing lab groups and then applied these findings to form educational implications. When students work within small groups (i.e. the first few diagnosis work days), they tend to generate explanations, develop meaningful vocabulary, and create shared knowledge. In contrast, the repeated case studies and competitive aspect between groups simulated the inter-group discourses of practicing scientists and challenged students to justify their findings. "Claims are subjected to a process of competitive controversy…to gain factual status… and find a view the best holds out against criticism" (Woodruff & Meyer, 1997, p. 29). By cycling between small and large group discussion formats, students not only shared information, but were also engaged in a legitimate scientific process that challenged their dialectic discourse skills. Although this unit plan was designed to be enacted under ideal conditions, some limitations of time had to be recognized and so hands-on activities were sacrificed for adequate discussion time.

III. Student-Selected Poster Topic and Evaluation

Honoring the multi-disciplinary aspects of problem-based learning, as well as creating more opportunities for student-directed learning, I opted for the student groups to select one aspect of their two case study diseases to investigate in great detail. This information, in addition to basic information about the initial disease and pathogen, was presented as a group-created poster during a large poster session to both their peers and related professionals. One difficulty expressed by both of the subject teachers in the interviews was problems with formalized, summative assessment. While the many discussions and loose structure provide opportunity for many formative assessments, the group-based format and discourse-based framework are challenging to combine with a traditional grading system. In an attempt to mediate this problem, poster presentations generated a concrete artifact of student learning with which I could justify an assigned grade to an administrator, allowed creative and visual learners an opportunity to demonstrate their abilities, and summarized information about all five pathogens into succinct, visually-engaging exhibits that the students would be repeatedly exposed to throughout the presentation session. Although the guest evaluators would require significant work for the teacher, they bring an important sense of legitimate authenticity to the students' work that would help to ensure the production of quality posters (Chin & Chia, 2008). In addition, these experts would be able to engage the students in conversations in which I would lack the SMK necessary to participate. Finally, the entire poster and poster session experience models how real scientists present, share, and are evaluated on their work; this provides students with an experience that, if explicitly addressed, could help further students' understandings of the nature of science.

CONCLUSION:

This study investigated how designing and implementing PBL curriculum affected teachers with varied levels of experience. By analyzing interviews with experienced teachers, changing beliefs about problem-based learning's strengths, weaknesses, and implementation were noted. As individuals became more familiar with developing and enacting PBL, they were better able to communicate their personal beliefs about reform-based pedagogies and showed an increased ability to view PBL enactments from the long-term perspective. As a pre-service teacher, my ability to create a problem-based learning curriculum aligned with education theorists significantly increased between my first and second attempts. This growth could be attributed to changes in my grain-size perspective or to a more complete understanding about required teacher knowledge. This single account of a PBL development and enactment does not characterize the diverse and complex components of teacher knowledge and beliefs that lead to reform-based pedagogy but it does contribute to a practice-based definition of inquiry science teaching.

APPENDIX A: Interview Questions

February 2009: Pre-Development Interview Protocol With John

1. How would you define your teaching style?
2. Do you think there is a clear difference or rationale between your typical classroom style and problem-based learning?
3. What are you goals and expectations for developing this PBL unit?
4. Do you perceive any problems in the development of this unit? What about the enactment?
5. What do you think the most important aspects of PBL are? For your students motivation? Retention of knowledge? Ownership of material?
6. Are there any aspects of PBL about which you are unsure?

April 2009: Post Development Interview Protocol with John

1. We've been trying this for two days now, have your ideas changed at all about how to design PBL units? What about the goals of a PBL unit, have those ideas changed at all?
2. Do you think your students are benefiting from this unit in any ways aside from gaining information about microbiology?
3. Do you think there are benefits from a traditional classroom that you have to sacrifice in a PBL setting?
4. As of right now, part way through the unit, what can you identify as the strengths of this alternative teaching style? What are the weaknesses?
5. You had mentioned in the first interview that you wanted to have everything mapped out for this unit and that you typically work through all the small details before going into the classroom, has this mentality had to change with this process? If so, how are you coping with the relative spontaneity?
6. If you had to give a summary of the process, or a few words of advice to a new teacher getting involved in PBL, what would those be?

March 2009: Interview Protocol with Bill

1. How long have you been teaching? And how many to go?
2. How would you describe your teaching style?
3. Are you familiar with Problem-based learning as a teaching method?
4. Do you think you implement in your classroom? Or would you care to elaborate on your understanding of it?
5. Do you think that there is a strong difference between these teaching methods and your typical style in the classroom or do you think that it's very well-integrated into the way your classroom normally functions?
6. What are your goals for your students, aside from academically this school year, but more far-reaching?
7. Inquiry-based learning and problem-based learning are both really popular terms in teacher prep programs right now. I was curious as to how you differentiate between the two; really if you differentiate between the two? And could you give examples?
8. Do you think PBL is more effective?
9. Do you find any resistance or problems from students in using PBL?

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