Project Based Learning Approach to Shale Diagenesis: A Better Avenue to the Big Picture

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ABSTRACT

This article describes an experimental six-month study that was created to introduce first semester graduate students to geological research in fine-grained rocks. The study was conducted within a graduate-level Clastic Diagenesis course where students examined the mineralogical and chemical variability in shale samples that crop out in regions of different thermal maturity along the Ouachita Mountain Fold Belt. A project-based instructional (PBL) approach was used with a driving question of "what happens to shales during burial diagenesis?" This approach was intended to give students an opportunity early in their graduate studies to participate in authentic geologic research. Each sample was analyzed for the clay-mineralogy using XRD, whole-rock chemistry using XRF, mineralogy of heavy separates, character of the silt-sized quartz and feldspar, and grain size of the non-clay fraction.

Qualitative data analyses from student interview transcriptions revealed that based on their experience with the Ouachita project students were able to approach their own thesis topics, regardless of the subject area with a more holistic and experienced scientific perspective. The depth and quality of the research questions they asked in their own subsequent research was influenced by their exposure to the clastic diagenesis problem-based project. Developing competency in the analyses techniques was not the goal of this project but rather developing an overarching understanding of the process used when studying the diagenesis of fine-grained rocks. Evidence that this was achieved is demonstrated in the student’s final presentation of the Clastic Diagenesis project at a regional geologic meeting.

INTRODUCTION

An experimental six-month study was conducted at the University of New Orleans to introduce first semester geology graduate students to research in sedimentary petrology. Five students enrolled in a graduate Clastic Diagenesis course completed a study on the Mineralogical Variations in Ouachita Shales using a project-based learning (PBL) instructional approach. The study involved examining the mineralogical variation in shales that were known to occur in areas of differing thermal maturity along the Ouachita Mountain Fold Belt in southwest Arkansas and southeast Oklahoma. This approach was intended to give students an opportunity early on in their graduate studies to participate in authentic scientific inquiry and therefore set the stage for how to approach a thesis research problem.

The concept of "authentic" geologic research implies that the cognitive demands (the thinking required) placed on the student, are consistent with the cognitive demands that are expected in the geologic community for which we are preparing the student (Honebein, et al., 1993). Thus, we do not want the student to learn solely about the historical, textbook background on the clastic diagenesis of fine-grained rocks but rather to engage in scientific discourse and problem solving that researchers use to construct interpretations in this field.

A PROBLEM-BASED LEARNING APPROACH

The problem based-learning instructional approach used in the clastic diagenesis course is grounded in a constructivist theoretical framework. Constructivism is a cognitive theory on how we come to understand or know. The body of literature on constructivism is voluminous and extensive and therefore a summary of the constructivist view is presented via the following three central concepts: 1) our understanding is directly connected to our interactions with the environment, 2) social negotiation is critical to the evolution of knowledge and 3) cognitive conflict created by multiple perspectives is the stimulus for learning and how knowledge is organized (Savory and Duffy, 1995).

Constructivism focuses on the idea that learning never occurs in isolation and the elements of the surrounding environment such as the context, the activity of the learner, and the goals of the learner all contribute to how the learner constructs meaning and knowledge. The perspectives of collaborators therefore profoundly affect individual understanding, and this is why working in groups is encouraged in PBL for it allows the testing of individual ideas and the ideas of others. This testing serves as a mechanism for interweaving perspectives, which results in a greater understanding of particular phenomena. The social negotiation of alternative perspectives within a group also implies that all views are not equally viable and that social negotiation is driven by the goal of obtaining the collectively most viable understanding (vonGlastfeld, 1989).

The constructivist core concepts summarized above can guide instruction and the design of optimal learning environments. These concepts can be expanded into the six following problem-based instructional principles (Lebow, 1993), all of which were used as a guide in the Clastic Diagenesis project: 1) Anchor all the learning activities to an overall problem. Learning must have a purpose and relevance other than the acquisition of a grade. This is an important transition from undergraduate to graduate studies. 2) Facilitate student ownership for the overall task. Challenging students to validate or disprove research by introducing their new data to an area with an already published scientific interpretation is a successful strategy for developing ownership. 3) Create an "authentic" task where authenticity comes from working on a research problem that is a genuine, viable question in the scientific community. 4) Do not simplify the environment but rather allow the natural complexity to exist. This idea reflects the importance of context in determining the understanding that a researcher develops of any...
The 1998 Boyer Report, especially in actual field or clinical settings. Boshuizen and Schmidt (1990) suggest that this type of clinical setting the information they learned early on. Overload, they lose their motivation, find it difficult to keep up in a rapidly changing field, (Bok, 1989). Coles (1985) and Newble and Clark (1986) report that students were more likely to use versatile and meaningful approaches to studying than non-PBL students, who were likely to use reproduction. Blumberg and Michael (1992) found that PBL students were more likely to use textbooks and other books and informal discussion with peers than did non-PBL students, who were more likely to rely on lecture notes. This instructional approach can be extracted from the medical field and used in other areas of science. In the 1990's the use of problem-based learning expanded into other fields including, management, education, law, engineering, and architecture. We have incorporated PBL into a project for first semester geology graduate students who are expected to make the transition into their thesis work often with limited research experiences and problem solving skills. Geoscience undergraduate programs typically focus on concept mastery and prepare students for success in traditional coursework. Some students participate in undergraduate research opportunities such as senior theses but many do not and consequently complete their baccalaureate programs with little if any research experience. Therefore, research areas where first-year graduate students struggle include: project management, problem solving, collaboration, and presentation of ideas. Using the PBL approach as shown in Table 1 instead of learning predominantly from textbooks and lecture in graduate courses has the following benefits: improved research and problem-solving skills, a deeper contextualized knowledge of the subject, increased self-direction, and greater information retention levels across time (Curtis, 2001; Bok, 1989).

Table 1: Phases of the problem-based learning cycle (modified from Arends, 2004).

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<thead>
<tr>
<th>Phase</th>
<th>General Behavior</th>
<th>Clay-Diagenesis Project</th>
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<tr>
<td>Phase 1</td>
<td>Professor goes over the objectives of the project, describes important logistical requirements, and motivates students to engage in self-selected problem-solving activity.</td>
<td>Presented the Ouachita project and its current scientific interpretation. Introduced the new portion of the project that students would be working on and how it related to the preexisting work.</td>
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<td>Phase 2</td>
<td>Help students define and organize study tasks related to the problem.</td>
<td>The professor offered a couple weeks of lecture and students further defined their individual roles in the project. Each student picked a portion of the project to assume ownership of.</td>
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<td>Phase 3</td>
<td>Encourage students to gather background literature on the problem and identify experts in the field.</td>
<td>Background research was conducted and a field excursion was planned collaboratively with site locations and all the planning done by the students.</td>
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<td>Phase 4</td>
<td>Analyze the data</td>
<td>After rocks were collected students prepared samples and conducted analyses with the help of local experts and the professor.</td>
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<td>Phase 5</td>
<td>Interpret the data</td>
<td>Students worked together to interpret their data results and how they fit into the already existing body of research on this project.</td>
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<td>Phase 6</td>
<td>Present artifacts and exhibits</td>
<td>Students prepared a poster for a regional conference and presented their data and findings.</td>
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<td>Phase 7</td>
<td>Reflect on the problem solving process used in the PBL project</td>
<td>Students were interviewed on their experience with the PBL project.</td>
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particular concept. 5) Encourage the testing of ideas against multiple perspectives. Because knowledge is socially negotiated, encourage discourse between students, and other experts in the area of study. 6) Support student reflection on both the content and the learning process. Interviewing students at the culmination of a PBL project can accomplish this. All of these principles can serve as a guide for incorporating problem-based learning. Table 1 presents a modified outline from Arends (2004) that offers a five phase instructional PBL approach that can be implemented in any project driven course. The project-based learning approach had its start in the 1960s at McMaster Medical School where faculty were frustrated with the quality of the student preparation they were providing (Schmidt et al., 1987; deVolder and deGrave, 1989; Barrows and Tamblyn, 1980; Bok, 1989, Boud and Feletti, 1991). It was preferred over traditional didactic teaching (TDT) because it recognized that students retained minimal information and had difficulty transferring knowledge to new experiences with TDT (Schmidt, 1983). One of the major criticisms of traditional lecture-based education was the encouragement of "a passive, static attitude toward learning that emphasized memorization instead of the active, inquiring approach that the mind required to keep up in a rapidly changing field," (Bok, 1989). Coles (1990) describes that much of medical education is memorization of facts and data, often composed of abstract information, which is to be applied clinically at a later time. He explains how, "the students experience overload, they lose their motivation, find it difficult to see the relevance of what they are being taught, and later on experience difficulty in retrieving and applying in a clinical setting the information they learned early on." Boshuizen and Schmidt (1990) suggest that this type of education results in a professional that possesses a knowledge that he or she may be unable to access during application, especially in actual field or clinical settings. The 1998 Boyer Report, Reinventing undergraduate education: A blueprint for America's research universities, articulates the need for students who can think critically, solve problems, and work in teams and recommends problem-based learning as a vehicle for improvement (The Boyer Commission, 1998). Coles (1985) and Newble and Clark (1986) report that students were more likely to use versatile and meaningful approaches to studying than non-PBL students, who were likely to use reproduction. Blumberg and Michael (1992) found that PBL students were more likely to use textbooks and other books and informal discussion with peers than did non-PBL students, who were more likely to rely on lecture notes.

This instructional approach can be extracted from the medical field and used in other areas of science. In the 1990's the use of problem-based learning expanded into other fields including, management, education, law, engineering, and architecture. We have incorporated PBL into a project for first semester geology graduate students who are expected to make the transition into their thesis work often with limited research experiences and problem solving skills. Geoscience undergraduate programs typically focus on concept mastery and prepare students for success in traditional coursework. Some students participate in undergraduate research opportunities such as senior theses but many do not and consequently complete their baccalaureate programs with little if any research experience. Therefore, research areas where first-year graduate students struggle include: project management, problem solving, collaboration, and presentation of ideas. Using the PBL approach as shown in Table 1 instead of learning predominantly from textbooks and lecture in graduate courses has the following benefits: improved research and problem-solving skills, a deeper contextualized knowledge of the subject, increased self-direction, and greater information retention levels across time (Curtis, 2001; Bok, 1989).
COURSE DESCRIPTION

Clastic Diagenesis is a graduate level class designed to introduce students to the mineralogical changes clastic rocks typically undergo during burial diagenesis. The course has been taught multiple times by the researcher, usually in a standard lecture-lab format. Both sandstones and finer-grained rocks are covered, but as the research of the co-author has concentrated on mudrocks, their corresponding coverage in the course has increased.

Students bring many preconceptions regarding mudrocks to this class. This is primarily due to the limited coverage they receive in the typical undergraduate curriculum. Perhaps the biggest misconception is that mudrocks are composed entirely of clay minerals. A significant body of literature to the contrary exists (Blatt, 1992), but has not been incorporated into very many undergraduate texts. Active investigation into the actual mineral make-up of shales is an ideal way to address student misconceptions. The course during the semester covered in this paper was approached from this point of view. A research question was posed to the class, "What happens to a shale during burial diagenesis?" The formation to be studied was provided by the professor, the background research became the responsibility of the class. This was vital to the success of the project. The formation to be studied should be well known to the instructor, and robust enough to facilitate multiple research thrusts by the students. The research question became the theme of the class, the search for the answer the major goal. The instructor had a general expectation of the answer to the research question from the results of previous work, even though the actual answers would be answered by the research conducted by the class.

In this case, the Stanley shale of the Ouachita Mountains of southwest Arkansas and southeast Oklahoma was chosen for study because it met the following conditions. The Stanley outcrops over a wide area, it exhibits variable thermal maturity, and it has been extensively mapped with identified outcrop locations. Figure 1 illustrates the variation of thermal maturity across the Ouachita Mountains, and the availability of outcrop locations based upon sample sites from previous studies.

The class had three weeks to research the geological background, collect the maps, and plan a sample collection field trip. Class meetings during this period were spent discussing the Stanley formation and the relevant previous literature. Measures of thermal maturity, including vitrinite reflectance were introduced. Using published maps with vitrinite and illite-crystallinity contours (Houseknecht and Matthews, 1985; Guthrie et al., 1986) the students planned the sampling trip, including all stops, camping areas, and other logistical information. Every student at each stop collected samples. We returned with more than enough rock for multiple analyses.

Upon return from the field, each student became responsible for a separate laboratory method of investigating fine-grained rocks. This step is also vital to the success of the PBL experience. The choice of analytical procedures is dependent on many factors, not the least of which is availability. We were particularly interested in collecting information about mineral fractions that could be compared to other mineral fractions across a range in diagenetic grade. In addition, the choice of which student would be responsible for which specific set of analyses is important to the success of the class. The students were intimately involved in these decisions; however, a certain amount of orchestration by the instructor is beneficial. The preceding three weeks of class, combined with the more personal interaction of the five-day sampling trip, aids the instructor in facilitating these decisions. Ultimately, it is important for the students to take ownership of these decisions.

After several alternative analytical procedures were discussed and rejected, five procedures were chosen for the class study. These included:

1. Whole-rock geochemical analyses by XRF
2. Clay-mineral identification by XRD, including determination of illite crystallinity
3. Heavy mineral separations using LMT (Hanan and Totten, 1996), followed by SEM mineral identification
4. Quartz and feldspar separations by Na-bisulfate fusions (Totten and Blatt, 1993), followed by SEM identification
5. Grain size analyses of the non-clay fraction (Blatt and Totten, 1981)
1) Explain the overall Clastic Diagenesis course project and what your role was. How was the project conceived? What else was included in the course?

2) How many graduate classes have you taken so far that follow this style of teaching? How are your other graduate courses taught?

3) What did you like or dislike about the project-based approach to learning clastic diagenesis? Be specific.

4) Do you think you learned as much about clastic diagenesis using this approach than you would have if it had been taught like a traditional graduate course?

5) How did students with such differing backgrounds work together on the project?

6) What would you do differently to improve this approach to learning clastic diagenesis?

Table 2. Clastic diagenesis interview questions.

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<tr>
<th>Graduate Student</th>
<th>Question 2: How many classes have you taken so far that follow this style?</th>
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<tr>
<td>Student 1</td>
<td>This is the only graduate class where I have actually done science. In my undergraduate degree in sedimentology I did a project where we did the same work that has been well documented so we knew what to expect. That wasn’t the same thing. Here we were doing real science without knowing what the answer would be. Most graduate classes are lecture, reading, and some tests. There were readings in the Clastic Diagenesis class. I think Matt lectured a total of 2 times and he gave us a series of pertinent papers and sent us off to find more in the literature. One thing that really set the tone early on in the course and made a huge difference to me is when Matt said you all are colleagues and scientists, you have degrees in geology and this is your project. This got us out of the student mode and I really felt like I was a scientist and doing real science and not just a student learning info that one day would be used to do science.</td>
</tr>
<tr>
<td>Student 2</td>
<td>This is one course that wholly uses this style. Metamorphic petrology class did the analysis of eclogite and Chris had the samples, did SEM probe work, Fe and Mg garnets and pyroxenes to calculate pressure temperatures (1 month) wrote paper for Chris. We got into groups of 4 and assigned us our region for the eclogite piece. Looked for previously published papers on our areas. Other graduate courses are set up like undergraduate courses, seminars, lecture, some lab, and then tests and some home works. No possibility to publish.</td>
</tr>
<tr>
<td>Student 3</td>
<td>I have not had a graduate - or undergraduate - class experience quite like this one. All of my other grad classes were taught in the ‘traditional style’; that is, they leaned heavily on lecture and reading assignments to educate students, augmented in varying degrees by in-class participation.</td>
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<tr>
<td>Student 4</td>
<td>None. I have had classes that have involved mainly lectures and paper projects such as reports, poster projects, and tests. There have been a few classes that involved field trips that were very beneficial to understand the material.</td>
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<tr>
<td>Student 5</td>
<td>This was the first and only course I have taken in this style of teaching. My other graduate courses were the traditional lecture and exam style.</td>
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Table 3. Sample interview transcription.

Students were encouraged to help one another with any portion of the lab work that they were not specifically responsible for. All five procedures had a technician or faculty expert available to assist the class. Demonstrations of sample preparation, followed by supervised practice by the students, were shown before actual data were collected. Additional sample aliquots, appropriate to each analytical technique, were analyzed for sample precision and accuracy determinations. In a few cases, poor technique led to questionable data. These samples were reprocessed with the assistance of the technician.

The students are certainly not “experts” in any of these procedures at the end of the course, and required different amounts of help to collect their contribution to the course dataset. They were very enthusiastic about the process, and conscientious about the quality of their particular data. As the data were collected, class meetings were held to discuss preliminary results, and to incorporate any additional measurements that seemed appropriate.

An important component of the class was the synthesis of all of the data collected. Relationships between different mineral components were investigated. The class collectively submitted an abstract to the south-central sectional GSA meeting, and collaborated on the preparation and presentation of a poster at that meeting. This final presentation was an indicator of the success of the PBL project in that it demonstrated that students understood the process, the context, and the relevancy of the research that they generated.

QUALITATIVE EVALUATION OF THE COURSE

PBL presents some unique challenges for assessment. Because the focus of this pedagogy is primarily on learning to learn and less on mastery of a particular body of knowledge, traditional methods of course assessment such as examinations are not very effective (Major, 1999). Structured student interviews, a final project presentation, and feedback from experts associated with the project were the assessments used to evaluate the impact of the PBL approach in the clastic diagenesis course. Six interview questions were administered at the end of the course. The interview questions are shown in Table 2 and were done with a population of five, first year geology graduate students at the University of New Orleans. Responses were collected during 30-40 minute
Learning. The hands-on approach gave the students than a memorizing for the exam only approach to retained a lot of what they learned in the course because variations in shales. A few students commented that they learn the basics and a contextualized application as to looking to enhance. Some commented that you do not need to define what type of student learning we were this question were mixed. Student responses revealed a thesis and how to manage the difficulties that could crop this project allowed for vision of our own individual techniques previously in this course, "The experience in confident and prepared because they had used the work they did, "Other graduate courses are set up like an abstract from the work they did, "Other graduate courses are set up like undergraduate courses, seminars, lecture, some lab, and then tests and some homework, all with no possibility of publishing." This was the first time that any of these students had presented at a regional meeting and this professional experience initiated a comfort level with publishing." This was the first time that any of these students had presented at a regional meeting and this professional experience initiated a comfort level with presenting later in their graduate degrees at the following national conferences: Geological Society of America, Society of Vertebrate Paleontology, and Gulf Coast Association of Geological Societies. Exposure to lab techniques and equipment was noted in the interviews as something that students liked and learned a lot from. One student described the benefit of having time alone in the lab as well as with the group. This allowed for individual decision-making and coursework as well as collaborative group work. A couple of the students used some of the equipment again in their own thesis research, and felt more confident and prepared because they had used the techniques previously in this course, "The experience in this project allowed for vision of our own individual theses and how to manage the difficulties that could crop up in our own projects." A couple of the students used some of the equipment again in their own thesis research, and felt more confident and prepared because they had used the techniques previously in this course, "The experience in this project allowed for vision of our own individual theses and how to manage the difficulties that could crop up in our own projects." One of the questions that we were interested in exploring is whether students perceived their learning to be as great with the PBL approach compared to traditional didactic instructional approach. Responses to this question were mixed. Student responses revealed a need to define what type of student learning we were looking to enhance. Some commented that you do not learn as much textbook facts as a traditional class but you learn the basics and a contextualized application as to when and how diagenetic factors affect mineralogical variations in shales. A few students commented that they retained a lot of what they learned in the course because it was done in a hands-on application approach, "A working knowledge also stays with you much longer than a memorizing for the exam only approach to learning." The hands-on approach gave the students a better understanding of the science techniques that they read about in scientific journal articles, "I can read a paper and get info from it, but I don't have the depth of understanding of what the paper is talking about like I do with my own project." Some of the aspects of the PBL approach were also viewed as difficult. A few students commented that the project needed more structure at different places. One student wanted more of a structured lecture, "I've adapted well to the lecture environment and have to expect the dissemination of information in that manner. The informal lecture style used put me at a disadvantage because I didn't have notes to go to." A structured timeline was also suggested for the completion of different stages of the project. The need for more of a structured group organization was also expressed. Meetings were scheduled and not all five students could be present and some group dynamics formed as a result. Overall, the PBL approach provided a base for these five graduate students to start their own thesis work, "Your graduate work is suppose to focus on your thesis, but classes like these really help you get into the research and writing mode." Having a central,"defining question" required "everyone to cooperate and work collaboratively, "Just trying to get an "A" isolates you, working to put a poster together for a conference seems to make everyone meet somewhere in the middle. The sampling field trip also helped us to bond early on." The mixture of having collaboration with students of varying backgrounds proved to bring strengths and insights to the project, the diversity served the class well," Some members had very little experience with the microscope, some had done chemical separations before, these differing strengths complimented each other. In the semester following the course students put their conclusions together and created a poster presentation. This required the students to revisit and synthesize all of the pieces of data that they had individually generated. Constructing the poster provided an opportunity for a lot of discussion and interpretation of the data, as well as, learning skills of working with media such as Adobe Illustrator. Students presented their work at a sectional geologic conference and received feedback from other professionals. As a result of their work students showed that increased illite crystallinity corresponds to increased thermal maturity. Illite crystallinity was different than predicted from the previously published thermal maturity map at several sample locations. Based upon this new data the thermal maturity map was slightly modified. No correlation (R2=.129) was determined to exist between illite crystallinity and heavy mineral percentages. Quartz grains showed an increase in polycrystallinity versus monocrystalline grains as temperature increased, in agreement with previous work. No relationship was evident between whole rock silica percentages and illite crystallinity. **CONCLUSIONS** Findings suggest that the PBL approach was successful as evaluated by the five graduate students in a Clastic Diagenesis course at the University of New Orleans. The results demonstrate that a student-centered strategy can be a successful alternative to the traditional didactic teaching approach that is prevalent in graduate geoscience courses. Based on student responses, the PBL approach promoted better long-term knowledge retention and helped to structure information so that acquisition and recall were optimized. As a result of the
PBL approach, students could read the literature in this area and understand the research in a more meaningful way than if they learned about clastic diagenesis with lecture-based instruction.

There are some limitations with this study that include a small sample size and the evaluation process for PBL projects. Typically projects that involve graduate students will always have small sample sizes compared to those that utilize the introductory service courses. The best approach to reveal rich, deeper contextualized information is via the interview process where students discuss their perspectives in detail and at length. The trade off is, it is difficult to find and interpret valid acceptable measure of outcomes of PBL curricula. Testing with multiple choice instruments do not reveal problem-solving abilities and are not readily adapted to measuring process skills needed for critical thinking.

Another barrier to PBL is the effective implementation of the "professor as facilitator" process. Professors must adopt new roles that are frequently very different from those of their past. The professor acts as a model, thinking aloud with students, prompting them to take on responsibilities, encouraging independence, and then fading into the background to become another colleague on the team. Successful implementation is not easy and it takes practice with this style of instruction.

Project based learning experiences help students become more self-directed learners and promote integrated education. Few problems facing society that involve the geosciences are aligned within disciplines. Subsequently, students need to be able to solve problems that require them to make connections and use relationships between concepts and content. Students that learn information via the PBL approach are better able to do this. This is perhaps the most important goal in graduate school is for a student to be able to recognize how their knowledge and expertise relates to the big picture.

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