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Collaborative Course Design and Inquiry-Based Approaches in Geoscience Education

by Paul E. Baldauf and Robert Hill

Introduction

In recent years, the community of higher education has seen a rapid expansion in undergraduate programs focused on nontraditional age students. The principal features of these programs are reduced residency requirements and pedagogical strategies aligned with the needs of adults. Such approaches vary with programs and institutions. Union Institute & University (UI&U), for example, used a guided-independent tutorial approach; University of Phoenix uses collaborative learning. In some ways, these second- and third-generation adult programs adapt the correspondence model of education programs that has a long history in this country and continues to exist. However, these newer adult programs provide more learning structure and contact than previous generations of distance learning programs, without attempting to duplicate the traditional classroom experience in the home. While the quality of these programs varies, many like UI&U have firmly established educational philosophies rooted in progressive education. Nonetheless, low-residency, distance and online programs present challenges for disciplines requiring hands-on experiences, particularly the science, technology, engineering, and mathematics (STEM) disciplines. While the availability and distribution of learning materials through the World Wide Web (web) provide enhanced learning opportunities in the STEM disciplines, challenges remain for learners with limited access and proficiency with technology.

UI&U is a private, nonprofit independent university with a history of research and practice in progressive education. UI&U descends from a consortium formed in 1964, The Union for Research and Experimentation in Higher Education--the original "University Without Walls." By the mid-1970s, the consortium dissolved into a freestanding institution named The Union Institute, then, recently UI&U. UI&U undergraduate programs typically use a guided-independent tutorial learning strategy, defined here as a low- or non-residential course with one-on-one contact with faculty via telephone or email. At the inception of this project, UI&U was beginning to move towards an online support platform called eCollege, but only a handful of courses had been developed by faculty for this platform. The Florida Academic Center of UI&U is an urban campus located in North Miami Beach, Florida. The majority of our 250 undergraduate learners came from South Florida, the Caribbean, Central and South America. At the time of this study, approximately 66% of the learners were African-American or Caribbean Black, 14% were Hispanic, and 20% were white, non-Hispanic. Approximately 80% of the learners were women. Nearly half of the enrolled learners were elementary, secondary, or exceptional-student education majors.

Goals and Objectives

Working with UI&U learners in tutorials and observing them during their student teaching internships, we recognized we were not achieving good results in our science education program. While this seemed an especially difficult situation at UI&U, pre-service teachers face similar challenges at most institutions. First, nontraditional education learners are often poorly prepared for science courses at the college level. Secondly, education majors often come from groups (women and minorities) traditionally not well served by STEM education. Finally, experience suggests that only a fraction of students respond well to the tradition lecture-lab-exam style of most university science courses. Independent tutorials at UI&U duplicate many of the least successful elements of a typical college science course: reading assignments and problem sets from a college textbook, followed by a take-home examination. Weak students often failed to contact professors to discuss their work, forfeiting a crucial learning opportunity in this pedagogical system.

To strengthen science education pedagogy and meet the needs of our pre-service teachers, we proposed to work collaboratively with our learners to revise our introductory Earth Science course (SCI 105) from a guided-independent study course to a whole class model which would include active inquiry- and problem-based learning assignments consistent with local, state, and national content and technology standards. The change to a hybrid online pedagogical model was a significant departure from the standard pedagogy of the undergraduate program. However, we had ample evidence (shown below) to suggest our independent learning model was not helping our learners become better science

learners or educators. Initially, we hoped this work might serve as the foundation for an institutional shift in approach to science education and other areas of the university curriculum. To support our overarching goals, we identified the following course objectives:

1. Learners will use online data to analyze and interpret geologic processes active in South Florida;
2. Learners will demonstrate growth in their knowledge, skills, and understanding of technology;
3. Learners will use technology and active learning assignments to engage in scientific inquiry;
4. Learners will work collaboratively and cooperatively with peers and instructors to enhance their learning experiences; and
5. Learners will identify ways in which course content and processes can be integrated into the K-12 classroom.

Educational Technology in Pre-service Teacher Preparation

In addition to science, educational technology preparation is another important component in the degree programs of pre-service teachers. In an effort to increase usage of technology in teaching and learning, many states including Florida now require pre-service teachers to demonstrate proficiency in alignment with the National Education Technology Standards (NETS) created by the International Society of Technology in Education (ISTE) (ISTE, 2000). The revised version of SCI 105 Earth Science was offered as an online course in eCollege (a course management system), which includes online course content as well as asynchronous discussion, synchronous chat, links to web sites outside the course space, grades, quizzes and tests, and multimedia materials. We were fortunate to have a member of the Instructional Technology group as a collaborator to help us align our curriculum and pedagogical goals with best practices in online education.

Inquiry- and Problem-Based Learning

In recent years, professional and policy organizations such as the National Academy Sciences (NAS) and the American Association for the Advancement of Science (AAAS), as well as National Association of Science Teachers (NAST) have recommended educators move away from traditional lecture formats to more inquiry-based styles of teaching. Colburn (2000) defines inquiry-based instruction as the "creation of a classroom where students are engaged in essentially open-ended, student-centered, hands-on activities" (p. 42). The National Research Council's (NRC) science education standards (NRC, 1996) state that learning science is an inquiry-based process and that learners should: 1) describe objects and events, 2) ask questions, 3) apply knowledge, 4) construct explanations of natural phenomena, and test those explanations in many ways, and 5) communicate ideas to others.

We identified inquiry-based learning and problem-based learning (PBL) as effective means of enhancing the university's independent tutorial pedagogy. PBL has been used widely in higher education to prepare future physicians and other professionals (Wood, 2003). The term PBL has been used by education professionals to refer to a variety of problem- and scenario-based teaching strategies. However, the Association for Supervision and Curriculum Development (2004) defines PBL as "focused, experiential learning (minds-on, hands-on) organized around the investigation and resolution of messy, real world problems." Bridges and Hallinger (1995) posit that unlike traditional instruction where teaching is viewed as the transmission of knowledge and learning as the acquisition of that knowledge, PBL involves both knowledge and practice, as program designers assume that learners bring knowledge to each learning experience.

For a variety of reasons, many educators familiar with PBL are reluctant to adopt this strategy in the classroom. PBL pushes students into an active role in the classroom and, as a result, the role of the teacher is markedly different in the PBL classroom. Furthermore, while PBL does not reject the importance of content, this strategy does reject learning through memorization of information in preparation for later application (Margetson, 1997). As a consequence, some educators, students, and parents have expressed concerns about student preparation for standardized and certification examinations. However, the literature seems to suggest that students in PBL classrooms achieve comparable or better results on standardized exams than students from traditional classrooms (Schneider, Krajcik, Marx, & Soloway, 2002). Nonetheless, while good learners respond well to PBL assignments, we are convinced that PBL is no panacea for weak learners.

Previous Work: Building Support for Change

In 2003, we received a faculty research grant from UI&U for a needs assessment of the science education curriculum within our undergraduate program. Initially we requested money to develop a science foundation course built around inquiry-based activities and emphasizing scientific method, to improve the attitude of UI&U learners towards science and instill inquiry-based pedagogy. For our needs assessment, we used three approaches. First, we reviewed the professional literature, including standards used by state-approved programs in the State of Florida. We compared these to national goals and standards prescribed by, among others, the National Research Council (NRC) of the NAS (NRC, 1996) and the AAAS (1993). Second, we created a science attitudes survey for our pre-service teachers and administered the survey during the preparation course for the student teaching internship. We also sent attitudinal surveys to our alumni who were currently teaching elementary school in M-DCPS. Finally, we arranged a series of interviews with faculty and administrators at other institutions to discuss concerns, challenges, and best practices. We interviewed science department chairs from private, public, traditional, and nontraditional schools, as well as district administrators responsible for science education in Miami-Dade County Public Schools.

Surveys of Our Learners

As part of this project, we surveyed UI&U education learners, prior to their student-teaching internship, on their attitudes towards science and their preparation for teaching natural science in the elementary school classroom. Results shown in Figure 1 below indicate our pre-service and in-service teachers lack confidence in their ability to teach science in the elementary school classroom (Baldauf & Hill, 2003; Hill & Baldauf, 2004; & Baldauf, 2004). We attributed their lack of confidence to our failure to either build strong content knowledge or to give them inquiry tools for teaching science in the classroom. As relatively inexperienced learners, our pre-service teachers could not master inquiry techniques without further guidance. We resolved to revise the Earth Science course to provide more structure and more opportunities to engage in inquiry and to work collaboratively with other learners.

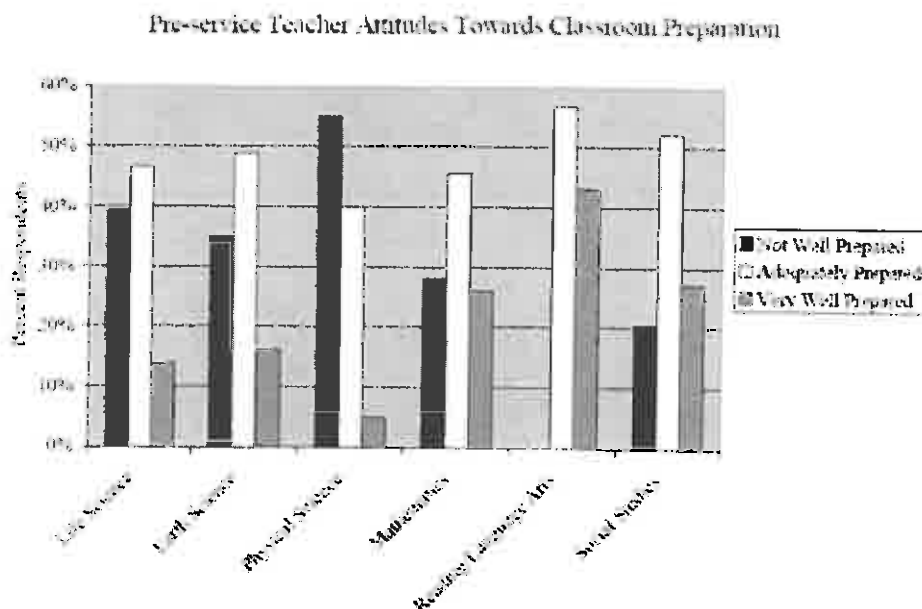


Figure 1 - Pre-Service Teacher Attitudes towards Classroom Preparation

Results of Interviews

In addition to our learner surveys, we contacted faculty and administrators from traditional and comparable nontraditional institutions to discuss general education science requirements and issues in science education. We interviewed Dr. Gustavo Loret-de-Mola, the District Science Supervisor for M-DCPS, supervisor for the science education and curriculum for Miami-Dade County. We asked him eight open-ended questions regarding the efforts of the district to improve education. His suggestions for improvement included teacher preparation in pedagogy and content knowledge. He recognized that most elementary school teachers do not feel comfortable teaching science or mathematics. He also added that pre-service teachers need to experience more mock classroom situations and field experience. In contrast to Dr. Loret-de-Mola, Dr. Susan Mussoline, a Title I Coordinator at a large local elementary school in the M-DCPS, felt that most teachers are adequately prepared. Significantly, she identified lack of time for teaching science as the greatest challenge to science education in M-DCPS.

For faculty perspectives, we interviewed Dr. Brenda Moore, Assistant Professor of Biology at Antioch University (AU) and Dr. Grenville Draper, Professor of Geology and an Undergraduate Academic Advisor at Florida International University (FIU). These science professors teach, among other courses, the university's general education science courses. They felt that, overall, non-science majors consider science irrelevant and approach science with varying levels of preparation. Together, challenges they identified were 1) large class size, 2) lack of research lab equipment, and 3) overcoming the stereotype that science is "nerdy" and irrelevant.

Instruction on inquiry and scientific method at FIU and AU varied. FIU required two science courses (each with a lab component) to fulfill the general education science requirements. The two most popular courses in the curriculum were Introduction to the Earth and History of Life (a biological science course). In contrast, Antioch University required only one science course; Practical Nutrition and Everybody's Chemistry were the two most popular courses in its curriculum. Like Antioch, UI&U required only one science course; nutrition and environmental science were the most popular courses. Ultimately, using these data, we were able to convince our dean and provost to support curriculum changes to the science education program.

Methods

Adaptation

Based on a review of the literature, we chose to adapt the course materials from a course entitled GEOL/METR 309 Investigating Land, Sea, and Air Interactions developed and taught by Dempsey and White (2001) at San Francisco State University (SFSU) as part of a National Science Foundation funded Course, Curriculum, and Laboratory Improvement grant (DUE 0127160) (<http://funnel.sfsu.edu/courses/gm309/>). Dempsey and White's approach suited our needs in a number of ways. First, Dempsey and White designed their course using inquiry and PBL approaches. Second, Dempsey and White's student population, like ours, was primarily pre-service teachers from urban school districts. Dempsey and White developed seven topical units and three hands-on field activities offered in a traditional, live classroom setting with materials distributed through an online course management system. They divided each topical unit into three phases: an initial investigative phase, a problem-solving phase, and an assessment phase. Course exercises covered a spectrum of self-directed, professor-directed, and collaborative activities. We contacted Dempsey and he agreed to advise us during the completion of this project. In addition to materials from Dempsey and White, we also adapted materials from the Digital Library for Earth Systems Education (DLESE), from The National Science Digital Library (NSDL), and Multimedia Educational Resources for Learning and Online Teaching (MERLOT). We also attended a conference hosted by the University of Delaware to learn best practices in inquiry-based learning. In 2005, we submitted a proposal to NSF for support for faculty development, science education equipment and technology, and curriculum revision. We received a grant in the amount of \$85,000.

SCI 105 Geoscience Course Design

Like Dempsey, each module in our revised course included three learning phases: an investigative phase, a problem-solving phase, and an assessment phase. In contrast to Dempsey's course, we moved the investigative and assessment phases to the online course platform, focusing our class time on hands-on, collaborative activities. In the investigative phase of our course, learners met lower-order goals through online research and background reading from the assigned text or online materials. Learners also engaged in simple technology activities such as plotting data in a spreadsheet or taking online quizzes. Learners were guided in their investigations by online instructions, including explanations for skills such as plotting of data, use of spreadsheets, and other technical or technological skills. The investigative phase helped learners meet technology and content goals numbers 1, 2, and 3.

The problem-solving phase consisted of activities that integrated content and inquiry goals numbers 1 and 3. Problem-solving activities built on information acquired during the investigative phase and applied that knowledge to hands-on activities. The planned activities, mostly adapted from Dempsey and White, incorporated an inquiry- or PBL strategy that encouraged learners to discover relationships inherent in data sets from South Florida. These collaborative, face-to-face exercises met goal number 4 for cooperation and collaboration between learners in the inquiry process.

In the assessment phase, learners documented the outcomes of the learning experiences through a variety of face-to-face and online assignments, including response papers and online quizzes. The assessment phase insured that learners met our course goals for technology, content, collaboration, inquiry, and pedagogical strategies, numbers 1 through 5.

Collaborative Design and Committee Review

While we were confident that working with materials already in use at SFSU would help us create a better course, we worried that we still might create a course that was a good teaching experience for us but not a good learning experience for our learners. We worried especially about the increased technology expectations of this course. To help us keep the course relevant and keep our technology ambitions realistic, we worked collaboratively with a committee of learners, graduates, and faculty to evaluate the learning materials for the course as we were creating and adapting. Our goal was to involve all stakeholders, including learners, in the revision and adaptation process. We invited participation from graduates and current learners, ultimately settling on one graduate of the program who was teaching in an elementary school in M-DPS (see Figure 2), two faculty members and four current learners. Finally, we hired an outside evaluator to help us design survey instruments for the committee to use in evaluating the learning materials, and to lead a series of focus groups while we were not present.



Figure 2 - Evaluation Committee

The committee review process became an essential element of the assessment of the revised and adapted course modules. We planned for the committee to meet five times, each time reviewing one or more of the course activities or field activities (see Figure 3). We recognized that it would be impossible for the committee members to behave as if they were learners; nonetheless, we grouped them as we would the learners and asked them to interact with the course management software as if they were learners. Committee members met face-to-face at the Florida Academic Center and worked through each module. Drs. Hill and Baldauf facilitated each of the meetings, deciding on working groups where necessary, explaining the exercises, and, in some cases, offering brief lectures on the subject matter.



Evaluation

Figure 3 - Field Testing

The evaluation was designed to offer committee members the opportunity to comment freely on various aspects of the adapted course modules anonymously. Surveys consisted of Likert scale questions, short answer, and narrative questions. While each survey differed with the content and organization of the module, they generally followed the same format in order to make comparison of the responses easier across modules. Surveys covered the investigative assignments, course activities, assessment activities and general technology. Results of each round of surveys were used to help plan for the next meeting. Surveys were collected at the end of each face-to-face meeting and returned to the evaluator. The evaluator tabulated and summarized the results. We read these results during the planning and adaptation phase in preparation for the next meeting. In this way, we revised the tested modules and planned new modules incorporating the comments of the committee. An example of one of the surveys can be found on the course webpage http://faculty.tui.edu/baldaufp/NSF_Web.html.

We attempted to use a standardized procedure for the evaluation of each module. We divided the committee into groups for the hands-on activities. Group members read the online instructions for the problems and completed activities and assessments. In most, but not all cases, the committee members were asked to complete the investigative activities prior to coming to the face-to-face meetings. After each activity or assessment, committee members were asked to complete a survey. We did not read these, but gave them to the evaluator at the end of the meeting. The evaluator tabulated responses and summarized the findings. The evaluator distributed the tabulated data and findings to each member of the committee. Committee members noted issues relating to the lesson content and organization, as well as technology issues that emerged as they worked.

Results

Earthquake Lesson Inquiry-based Activity

For the Earthquake module, our goal was to create an environment where learners understood the fundamentals of earthquake occurrence and measurement. Although not stated explicitly, we wanted the learners to understand that earthquakes occur along faults when there was sufficient and rapid motion. We wanted our South Florida learners to understand that there is not a significant risk of earthquakes in our immediate area, but that the nearby Lesser Antilles faces some risk. In addition, we wanted our learners to understand that there is a measurable risk of tsunamis in South Florida, although the risk is not great. The course goals stated in the introduction to the module were:

1. Learners will use inquiry to solve problems using real world data,
2. Learners will use geologic concepts to analyze and interpret geologic processes common in South Florida, and
3. Learners will use technology to access data and research problems.

Specific goals for the activities were explained in a narrative format within a section entitled "Unit Overview." Those goals were given to the learners as: "... demonstrate that you understand 1) how earthquakes are measured, 2) why they occur, and 3) the pattern of distribution of earthquakes worldwide. In addition to these general scientific principles, demonstrate that you understand where earthquakes occur in or around South Florida, and what the risk is for earthquakes in the future."

The materials assigned for the investigative phase of the module consisted of selected readings from the textbook on earthquakes and a narrated PowerPoint presentation on tsunamis in South Florida. There was an initial assessment in the form of an online quiz that learners completed before the face-to-face meeting. Once in the classroom, the learners completed two collaborative activities using a jigsaw pedagogical strategy. The first problem-solving activity (Problem 1) asked that learners examine maps of earthquakes that occurred the previous week in the Caribbean around the Puerto Rico Trench (see figure 4). Learners accessed online resources at the United States Geological Survey (USGS) Earthquake Hazards Program webpage (<http://earthquake.usgs.gov/>). Maps of US seismicity allowed learners to view all the earthquakes that occurred in the US in past week. Learners were meant to discover that Florida has no earthquakes but the region just north of Puerto Rico is very active. The learners also accessed a map of Caribbean earthquakes occurring between 1990 and 2000 for comparison (see figure 5).

Problem-solving activity 2 (Problem 2) asked the learners to form four groups and separately investigate relationships between earthquakes and 1) topography, 2) patterns of earthquake, 3) distribution of volcanoes, and 4) age of the ocean floor (see figures 6 through 9 below). In this jigsaw activity, on completion of the first phase of the exercise, learners formed new groups of mixed expertise where learners from each discipline group contributed to a final report on earthquakes. Like

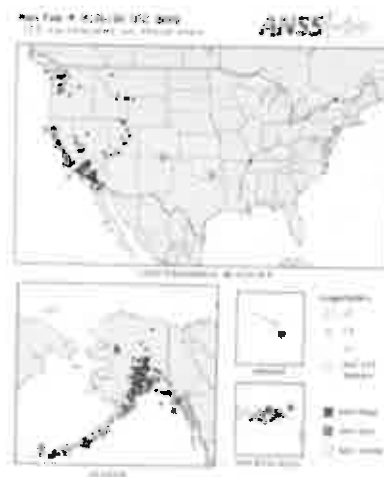


Figure 4 - Map of Earthquake Occurrence for Feb. 9, 2009

the first problem, this activity used resources from the USGS Earthquake Hazards Program. This problem was very similar to the one designed by Dempsey and White, substituting Caribbean earthquakes for California earthquakes. The assessment phase consisted of a post-investigative phase online quiz and a post-problem-solving reflective writing assignment.

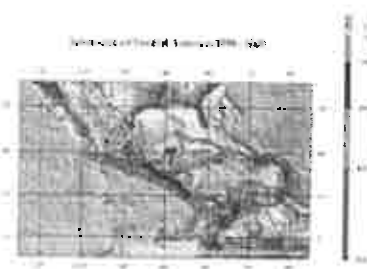


Figure 5 - Seismicity of Central America: 1990-2000

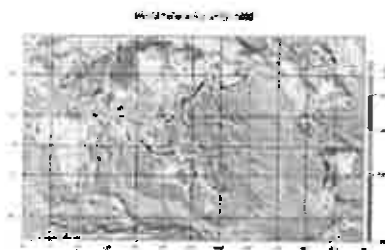


Figure 6 - World Seismicity: 1990-2000



Figure 7 - Volcano Occurrence

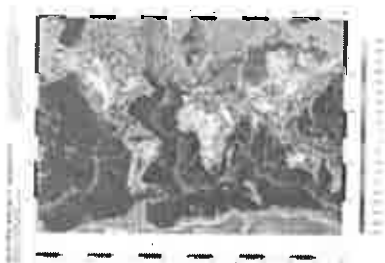


Figure 8 - Topographical Map



Figure 9 - Seafloor Age

Hurricane PBL Exercise

In addition to short-term inquiry-based units, the revised course also included a PBL exercise that ran for the entire semester. We introduced this problem in the first week of class and allowed time in each subsequent class meetings for the learners to meet and work on the problem. The problem was posed as a scenario in which the learners have been contacted by the mayor and police chief of Miami, who are in need of a group of experts to help them prepare for the upcoming storm season. Each learner worked in a group of experts, including meteorologists, geologists, biologists, and oceanographers to prepare a section of the report. Once the expert groups completed their research, we formed new groups with an expert from each group so that the final reports contained a section for each expertise. We provided a significant amount of support or "scaffolding" for the learners on this project. Each expert was given a list of relevant web links and books and articles. Finally, we provided the learners with a template for the final report and the goals for this unit:

1. Learn the process and conditions that lead to the formation of hurricanes,
2. Understand the hurricane risk for South Florida and the Caribbean,
3. Learn how we measure the intensity of a hurricane, and
4. Understand the hazards associated with hurricanes.

The introduction to the PBL assignment is given in the scenario below:

Miami-Dade County frequently feels the effects of the hurricane season in the form of near brushes with storms and even direct hits. Yearly residents are especially interested from year to year what they can expect from the hurricane season: will it be a busy season like the 2005 season, or will it be relatively quiet? Residents also want to know what hazards they can expect if there is a hurricane, and what they can do to

prepare.

In this assignment, you will play the role of scientists working in Miami-Dade County. You face the following scenario: the Miami-Dade Police Department has contacted your team of scientists, requesting information about the upcoming storm season. They would like a report from your team with a prediction for the upcoming storm season. Will it be busy and what hazards should they prepare for? Your job will be to work with your group of scientists to prepare a brief report including general information on the causes of hurricanes and their sources and the hazards produced by hurricanes.

Discussion

Investigative Activities

One consistent finding was that the evaluation committee often could not see a clear connection between the assigned investigative activities and the goals of the course or the hands-on activities. In the Earthquake module evaluation, for example, although the goals of the course and the outcome of the activities were stated at the beginning of the course and listed again in the overview of each unit, committee members found it difficult to connect the goals with the investigative activities. In modules developed later in the adaptation, we tried to strengthen the language and organization to make the goals more clear. However, committee members continued to have problems. Committee members were also critical of the textbook readings and found them difficult to understand and not relevant to the course goals.

Hands-on Problems

We planned for our learners to meet face-to-face with enough content knowledge to complete problem-solving activities. We also planned for learners to form hypotheses about the phenomena observed in the exercises. As a result, we did not design investigative activities to provide complete answers for questions raised in the problem-solving activities. Predictably, learner evaluators were frustrated when they realized they did not have all of the information or answers. In the Earthquake Problem 1, for example, we asked learners to explain worldwide distribution of earthquakes without having first covered the concept of Plate Tectonics. A discussion of Plate Tectonics, we felt, would limit opportunities for "discovery" in this activity. Committee members, some with prior knowledge of Plate Tectonics, were frustrated at this counterintuitive approach to the lesson, a frequent complaint of learners in the PBL classroom.

While committee members did not easily make the connection between course goals and investigative assignments, this was not true in the case of the assessment assignments. In most cases, as in the example of the Earthquake module, the committee found that investigative activities and problem-solving activities were assessed effectively.

Overall, we believe that working collaboratively with the committee of learners and faculty strengthened the design of this course and helped us anticipate problems during the rollout of this course. The committee supported our efforts as designers and acknowledged our successes in creating interesting and engaging activities. Anecdotally, the group understood our concerns for the quality of science education within the university at large and the education program specifically. With their help, we strengthened activities and clarified the instructions for every module in the course. Many of our experiences with the committee work were challenging as well. When we began, we hoped that we could create an environment where the learners could act as co-designers of materials for the course. More likely, stronger intervention would have been necessary to create a true collaborative working relationship with the learners on the committee.

Learners and our graduates also did not fully engage with the technology. The accounting system within the course management software, as well as anecdotal evidence, revealed that committee members did not engage with the course software beyond the minimum necessary to prepare for the face-to-face meetings. Furthermore, they rarely participated in the asynchronous discussions within the course units. While lack of engagement was discouraging, we believe that this helped us prepare for similar problems during the course rollout. The tutorial model that UI&U used for most of its courses was more flexible and easier for the learners than this hybrid course. We anticipated many learners would resent the additional rigor and structure of the approach we adopted, and they did. The lack of engagement we experienced with our committee members turned out to be a problem with learners as well. Anticipating this response, we continued adapting our approach each semester to improve clarity and strengthen learner engagement. We believe that even with the problems we encountered, our learners received a better science education because of this course.

Conclusion

Working collaboratively with learners to evaluate and design courses produced good results. Evaluation results were particularly helpful in highlighting problems with clarity of instructions and matching assignments to course goals. In contrast, designing course content with learners did not work as well. While this was a time- and resource-intensive process, it was an important step for us to predict the level of preparation of UI&U learners in working with new pedagogy and new technology.

Our results suggest that, not surprisingly, collaborative committee work with learners must be well organized to ensure good results. Our best results came from evaluation of content and activities, the most structured and focused of the committee activities. On the other hand, collaborative course design did not work. The informal brainstorming and

exchange of ideas produced frustration and few results. Collaborative design work with learners must be structured and focused, and possibly separated from the evaluation process.

Acknowledgements

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