Environmental Education Research
Vol. 14, No. 2, April 2008, 97–114

A case study of project-based instruction in the ninth grade: a semester-long study of intertidal biodiversity

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In this descriptive case study, project-based learning is presented as a teaching model that combines elements from other learning strategies. High school students participating in an intertidal monitoring project built around this model increased their content knowledge related to the ecology of the intertidal zone and improved their scientific investigation skills. Several aspects of project-based instruction are considered critical to success. Projects grounded in authentic scientific research develop scientific investigation skills through real world application. Alignment of scientific and educational goals enhances learning when the project is conducted in a sound pedagogical manner while maintaining scientific authenticity. Student teamwork builds a scientific community and makes the work more manageable. One of the most critical elements for success is a long-term commitment to project activities with connections between the project and related curricular topics. Flexibility of the school curriculum enables required content to be connected to the project's thematic base. These connections provide students with a common knowledge foundation and make it easier for educators to build such projects into their curricula.

Keywords: project-based instruction; constructivism; scientific inquiry; field ecology

Introduction

The need for helping all students achieve scientific literacy is compelling. Scientifically literate individuals can apply scientific knowledge and processes (Moss et al. 2001) to make sense of their daily lives and are equipped to face challenges 'head on' (AAAS 1990, xiii). Students who are scientifically literate understand the information gained through scientific investigation, but also how such investigation proceeds. In an examination of student conceptions of the nature of science, Moss et al. (1998) argued that instruction in the nature of science must be explicit, and connected to all other class instruction. To help students develop conceptions of scientific processes, teachers need to provide opportunities for this explicit instruction by allowing students to participate in the practice of science.

Despite a wealth of pedagogical research about the value of pursuing science education through scientific experience, stemming from the work of Dewey (1988 [1938]), modern science education has been described as preparing a few students to be future scientists rather than for preparing all students to apply scientific knowledge to their own lives (Millar and Osborne 1998). Barab and Luehmann (2003) outline the importance of questioning 'not whether learners should be doing science, but how best we can support and engage active learners in the process of doing scientific inquiry' (Barab and Luehmann 2002, 445). Quality environmental education must therefore be framed within learning theory and relevant research to be of value to learners (Brody 2005).

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ISSN 1350-4622 print/ISSN 1469-5871 online

DOI: 10.1080/13504620801951640
http://www.informaworld.com

The challenge to environmental educators, then, is to provide scientific experiences that will help build scientific and environmental literacy. Project-based learning (PBL) is a perfect fit in the science classroom. Providing students with challenging problems that lack simple answers engages them in productive problem-solving and fosters higher-order thinking skills and intellectual development (Barell 2003; Jenson 1998). When participating in research projects, students must determine how to solve problems, gather and organise information, and develop and test hypotheses. These practices promote ownership of knowledge and translate into critical thinking skills. Knowledge that students discover and build for themselves is also more meaningful and durable (Resnick and Chi 1988).

Edelson (1998) outlines concerns related to a lack of scientific authenticity in which learning is situational within the classroom and leads to an inability of students to apply their learning in real-world situations. Project-based learning can make learning relevant to the real world. There is a need for diverse experiences by learners in different environments, including local and personal environments such as home and school (Rickinson 2001; Payne 2006) to help them connect their local and personal experiences to global environmental issues. Students need to understand how living things are dependent upon one another and their physical environment so that they may develop a respect for nature and make informed decisions about using resources and technology wisely and sustainably (AAAS 1990). In the course of doing ecological research projects, they become environmental practitioners, so that as citizens they will have a knowledge base to draw on and make informed decisions about environmental practices (Orr 1994).

Project-based learning provides a framework for cohesively combining a series of educational strategies. First, PBL is constructivist in nature, providing students with opportunities to engage in the personal experiences necessary to build knowledge (Ballantyne and Packer 1996). The direct experience of PBL allows students to modify existing beliefs through experience (Richardson 2003). This incorporation of new knowledge into an existing personal body of knowledge is lasting (Lord 1999), and constructivism is a popular and promising approach to scientific instruction in general (Terwel 1999). In an examination of taking a constructivist approach to environmental education, DiEnno and Hilton (2005) found significantly higher knowledge gains and attitude changes for students engaged in constructivist experiences, noting the benefit to helping students gain skills needed for informed decision-making.

Both PBL and constructivist strategies incorporate some form of group or social interaction between students (Klein and Merrit 1994; Ballantyne and Packer 1996; Blumenfeld et al. 2000; Barab et al. 2001; Richardson, 2003). The incorporation of new knowledge in a constructivist framework requires that students have opportunities for interaction (Klein and Merrit 1994; Richardson 2003). The real world experience of PBL is enhanced when students engage in group discussion and activities as peers and colleagues, just as professional scientists do (Barab et al. 2001). In an examination of cooperative learning strategies used with high school students in Israel, Shachar and Fisher (2004) found that student achievement increased significantly when group instruction methods were used. Their study also indicated a decrease in motivation when these strategies were used. However, earlier studies of elementary students have demonstrated high motivation among students (Mastny et al. 1992), and Shacher and Fisher suggest that motivation might remain high in a system where group instruction strategies are the norm.

Another strategy that supports and connects to PBL is the use of student-scientist partnerships (SSPs). These cooperative partnerships between students and scientists align scientific and educational goals to engage students in research (Tinker 1997; Wormstead et al. 2002). In an identification of the components of SSPs that encourage success, Evans et al. (2001) emphasised the importance of direct contact between all participants, including teachers, students and scientists. This allows for the careful coordination by the teacher and scientist needed to ensure that the scientific and educational goals of the project are not in conflict (Baumgartner et al.

2006). As the teacher is usually the most frequent point-of-contact for the students and the director of the classroom curriculum, full teacher involvement is also necessary for success of PBL activities (Barab and Luehmann 2003). The SSP model is also in line with social learning suggestions of Krasny and Lee (2002) that environmental education teachers coordinate with professionals and volunteers to develop education programmes that achieve their goals.

In this paper, we present a case study of a project-based curriculum that incorporates elements from the instructional strategies outlined above to provide meaningful experiences for high school freshmen in marine environmental education. Following Kyburz-Graber (2004), we find the case study method appropriate to analyse this real-life, complex learning situation. The case we present falls in the descriptive model (Kyburz-Graber 2004) in which the events of a single unique project are examined. As an external analysis did not take place, we do not consider this an experimental case. Using the integrative model of Stevenson (2004) who summarised the case study categorisations of other researchers (Stake 1994; Yin 1994), this case is interpretive. We are seeking to gain understanding about the events described using an embedded single case design to examine the events in detail using multiple units of analysis.

Although Stevenson (2004) summarises the problematic aspects of case study research, including a 'failure to produce useful and transferable knowledge' (Stevenson 2004, 40) he noted that rigorous description can make a case useful to readers who seek transfer to their situations. We have followed the model of Kyburz-Graber (2004) who applied Yin's (1994) criteria for theoretical rigor of case study research. The theoretical basis of the case is the use of instructional models like PBL, SSPs, constructivism and social learning to answer research questions about the impact of those strategies on student learning. The research methods include pre-post assessments of student knowledge, products aligned to rubrics, and observations of students. Documentation of the case has occurred through presentation at multiple venues, and evidence of success presented via the results of concept inventories, student writing samples, and achievement on class projects. The logic of generalisation for this case is tied to the theoretical basis that uses existing research-based instructional strategies to develop an effective multifaceted structure for instruction. As the case spans two years, the differences between the first and second year help pinpoint successful instructional strategies. The heterogeneous nature of the class described in the case also provides some generalisation and transferability.

Case study

This case study examines a project conducted over two years at a small suburban charter school in Honolulu. The University Laboratory School (ULS) selects students through a stratified lottery to represent a cross section of the state's population with all socio-economic and ethnic groups represented, as well as varying ability and achievement levels, in a heterogeneous class structure. All students in this study were age 13–14, participating in a ninth grade marine science course at ULS.

Our Project in Hawaii's Intertidal (OPIHI) originated through the Graduate Teaching Fellowships in K-12 Education (GK-12) programme at the University of Hawaii. This National Science Foundation-funded programme partners science graduate students with local educators to provide enhanced science experiences for K-12 students and teachers while building the teaching and communications skills of the graduate fellows. The teacher and fellow in this case are the primary and secondary authors of this paper, respectively. Our project grew out of the fellow's research interests; in the course of her dissertation work on invasive invertebrates in Oahu's intertidal zone, she noted that little was known about intertidal biodiversity in Hawaii. Thus, students filled a much-needed research role by gathering data on intertidal organisms on the island of Oahu, Hawaii. A significant portion of our instruction involved training approximately 50 student field assistants each year to help with the labor-intensive job of surveying the intertidal zone for species richness and composition. This training encompassed the processes to be used in the research and the specific content knowledge needed for the students to put the project in perspective. Additional ecological content knowledge and learning related to the nature of science was gained authentically during the course of the project through direct discovery in the field and laboratory. This learning was extended to topics in ecology and marine sciences through related classroom activities.

By connecting all course instruction during the spring semester to OPIHI, we sought to provide the integrated relevant learning experience found to be lacking in many school curricula (May 2000). Our research goal for this case study was to determine whether students could gain knowledge about scientific investigation and embedded content by participating in OPIHI. The content embedded into OPIHI included basic ecological concepts like zonation and biodiversity and the specific methods used by scientists to study ecology and biodiversity. We also hypothesised that participating in a constructivist project-based partnership with a scientist and group collaboration would help students gain positive attitudes about the project content and doing science.

Project overview

In this case, we describe the activities of two OPIHI cohorts over two years. Each year, two ninth grade marine science classes with an average enrollment of 25 students participated in 6 field trips during the spring semester to collect data on the biodiversity of fish, macroinvertebrates and algae at intertidal sites around Oahu. The students sampled nine separate sites during the spring semesters of 2003 and 2004. Prior to collecting data, students participated in a series of lessons detailed below to prepare for fieldwork. We developed these lessons together to ensure mutually supportive scientific and educational goals.

Prior to the project start, we organised students into teams responsible for studying specific taxonomic groups of organisms found in the intertidal zone, such as fish, echinoderms, or mollusks. Students were assigned to these groupings based on teacher observations of student interactions during the fall semester and student input on preferred partnerships. Each group contained at least one high-achieving student, but all students in the group had tasks and roles to carry out, and peer review of group members was a part of the evaluation process.

To establish a foundation of student knowledge about intertidal organisms and scientific methodology, the first phase of OPIHI was a group project to investigate different taxonomic groups. Students examined live specimens of organisms in their assigned taxonomic group, developed questions by making observations, and performed simple experiments in the classroom. They quickly discovered which types of questions were unanswerable and developed questions that could be explored using basic equipment over a relatively short period of time. These mini-experiments engaged students early in the scientific process and helped develop their questioning skills. Student groups kept lists of observations and additional questions that arose during their experiments and expanded on their experimental knowledge through literature and Internet research about their taxonomic groups. Each group presented what they had discovered to the rest of the class, which provided accountability and helped build a learning community.

The next phase focused on trip planning, which we considered critical to developing student commitment to the field techniques and policies. This phase included hands-on activities to familiarise students with the sampling methods (outlined in Baumgartner and Zabin 2006). We included lessons in which students sampled jellybeans from a jar to understand the need for and potential pitfalls of the process. A second activity in which students searched the classroom for 50 individuals in 12 different 'species' (intertidal organism names written on index cards) of varying rarity helped emphasise the importance of standardising collecting techniques, replicating collections, and randomising site locations. To help students gain understanding of basic quantitative field techniques like point-intercept transects and point intercept and percent-cover quadrats, all students practised the techniques and reflected on the pros and cons of each. They then used a combination of all three techniques to conduct a survey of the school courtyard.

Students were also responsible for planning and compiling their own field collecting kits. Using tide tables to plan for optimal times to visit was an important part of planning that reinforced earlier learning about tidal influences and reading tide tables. Finally, background research by students on the hazards of visiting a rocky intertidal zone and the specific safety issues presented by the organisms in their taxonomic group culminated in a student-generated set of safety rules and preparation of a first-aid kit.

During field trips, student groups used the sampling techniques they had practised in class to collect data. The 2003 cohort focused only on developing a baseline of data on intertidal biodiversity by conducting general searches for algae, fish, and invertebrates. Each taxonomic team searched the same area for a pre-determined amount of time. Organisms were collected in buckets and identified in the field using local keys and field guides (see Randall 1996; Hoover 1998, 2003). Organisms that students were unable to identify on site were transported to the classroom for closer observation and identification using more detailed taxonomic keys. Volunteers from the University of Hawaii Botany and Zoology departments and the Bernice P. Bishop Museum checked the identifications of voucher specimens.

In addition to conducting general biodiversity searches, the 2004 cohort also used sampling techniques to quantify abundance. These were the same techniques that both cohorts had practised in the school courtyard: simple point-intercept transects, visual estimation of percent cover using .25 m quadrats, and counting organisms under 25 points within a quadrat. In cobble-dominated areas, we added an additional technique and turned a predetermined number of rocks along transect lines to count organisms living under rocks.

Student groups maintained field notebooks in which they recorded all information gathered during the project, including field data and organism identifications. When unable to make a positive identification, students would describe the organism thoroughly. Once identifications were made, students gathered biogeographic and ecological information on the species to examine patterns and hypothesise about possible reasons for those patterns, including human impacts, at the different sites. Near the end of the semester, students began to summarise and organise their data using information like vertical and biogeographic ranges of different species and whether species were endemic, native or nonnative. This information was used to synthesise information about sites and the overall project data for the final analysis portion of the project.

The emphasis on authenticity throughout the project required student assessment through authentic tasks. The 2003 cohort developed posters to share their work during an open house they hosted for other students, teachers, and parents. These posters were developed using professional software and printing techniques (Baumgartner 2003) and the students were completely responsible for planning and presenting the open house. The 2004 cohort students developed a web-based field guide to intertidal algae and animals. They first researched and critiqued a variety of field guides from various locations, and decided as a group which aspects were critical to include in their guide. Each student was then responsible for developing a page specific to a particular organism that had to include all the aspects of the field guide the class had deemed important. For both projects, as students had been functioning as a scientific community, they engaged in peer review of their work. Presentation of the work to an audience outside the classroom lent credence to the authenticity of the activity, and provided accountability beyond the classroom community.

Assessment of impact on students

In this embedded case study, we used multiple methods to assess student gains in content and skills knowledge. We prepared concept inventories of 50 concepts that we selected as related to intertidal ecology. Of these 50 concepts, two were duplicated for validation purposes, and we also included a set of concepts that were not addressed by the project. Students ranked knowledge on a scale from 1 ('I have never heard of this') to 5 ('I know this so well, I could teach someone else') at the beginning and end of the project period. Concept inventories were scored and the aggregate and individual scores compared pre- to post- using a two-sample *t*-test. To help us validate the reliability of the self-reporting, we also compared the change in rank for non-target concepts as a subset, using a two-sample *t*-test. A list of the concepts in the inventory and associated statistical overview is included in Appendix A.

The pooled aggregate concept inventories showed a significant increase in self-reported content knowledge (Figure 1). There was no significant difference in shifts between the two cohorts. The inventory concepts not covered in OPIHI had shifts that were significantly smaller pre- to post- ($t = 7.13$, $df = 44$, $p < 0.0001$) than those that were covered, and we feel confident that students were being reasonable and honest when reporting their understanding of concepts. These concept inventories indicate that students did gain content knowledge from PBL.

We did not examine explicit differences in content gained between this project and a more traditionally taught unit of study and cannot make any definitive statements at this time about improvements of our model of PBL over traditional teaching on content gains. To examine if student performance on traditional content exams was influenced by PBL, we randomly selected a content exam from a traditionally taught unit of study and a content exam from a unit embedded in the OPIHI project. We did not find any significant difference when comparing exam scores between the two exams using a paired *t*-test ($t = 0.919$, $df = 207$, $p = 0.179$).

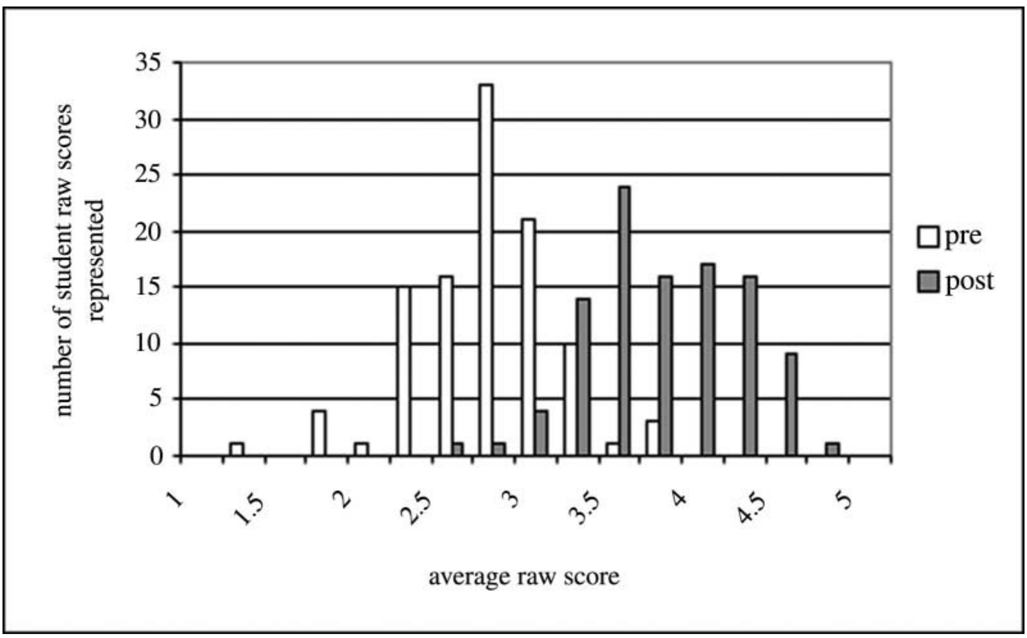

Figure 1. Average raw scores of concept inventories for pooled 2003 and 2004 cohorts pre- and post-project using a scale of 1 (I never heard of this) to 5 (I know this so well, I could teach someone else) for 50 concepts related to intertidal biodiversity and ecology compared using 2-sample *t*-test. $N = 104$; $t = 17.652$; $df = 105$; $p \leq 0.0001$

As another pre-post assessment of content and skills knowledge gained during the project, students completed essays answering the question 'How would you conduct a thorough study of the intertidal zone?' We scored the essays with a rubric for high, middle, and low goal achievement in three areas: awareness of surroundings and proper organism handling, general scientific methodology, and specific sampling methodology. We compared pre-post goal achievement using Chi-square. We were able to conduct a control comparison on instructional methodology between the two years on the sampling methodology aspect of the writing sample. This is because the 2003 class practised quantitative field techniques in the classroom, but did not use them in the field while the 2004 class used the techniques on multiple trips.

We saw a shift from predominantly low to middle achievement in all three categories (Figure 2) in both cohorts. Although shifts were significant in both years, these data were revealing about the impact of the instructional strategy. Pre-tests for both years showed no students with high achievement in sampling methodology, but the post-tests were quite different. Both cohorts had approximately the same number of students (18 in 2003, 17 in 2004) in the middle sampling category post-test. The 2003 cohort had 29 students who remained in the low category post-test and only 4 students with high achievement in the post-test. By contrast 11 students in the 2004 cohort remained in the low category with 22 students demonstrating high achievement post-test. Even though both cohorts practised the techniques on school grounds, students who had an opportunity to apply learned sampling techniques on the field trips gained a better understanding of sampling methodology than students who only learned about the techniques in class. The 2004 cohort students also could explain clearly why quantification was necessary to make comparisons across space and time. Although not statistically significant, the 2004 cohort also showed slightly higher gains in their demonstrated understanding of basic scientific thinking, but slightly lower gains in awareness of safety and animal handling than the 2003 cohort, who had spent more time collecting and handling organisms.

In 2004, we included an additional assessment by asking students to list what they knew about specific taxonomic groups at three points during the semester: (1) prior to any project work; (2) following book and internet research but before field work; and (3) following the field project. We matched individual student lists for each phase and recorded for each student the total number of concepts listed, the number of misconceptions listed or corrected and the number of concepts gaining sophistication during each of the three reporting periods. Determination of gains in sophistication was based on the original concept listed by the student. The concept was considered to have gained in sophistication if the student later added to their concept, used scientific language not previously employed, or described the concept using a higher level thinking skill such as synthesis or application in a new way. Gains in sophistication and corrections to misconceptions could only be analysed in phases 2 and 3 of the project. All of these items were compared with two-sample *t*-tests (Table 1(a)).

When asked to list what they knew about individual taxonomic groups, students listed significantly more concepts following the field project, and concepts that were listed early in the project significantly increased in sophistication following field research even though the book and internet research phase was more time-intensive than the field periods (examples from student lists are in Table 1(b)). These results showed that students corrected misconceptions themselves by conducting book and field research; direct teaching was not needed to correct misconceptions. In some cases, field research actually increased misconceptions, as when students concluded that crabs had variable numbers of legs, based on their observations of injured crabs in collections.

Beyond the formal collection of evidence described above, we made qualitative observations that indicate a positive impact of the project on student learning. These included reviews of student products like data notebooks, posters, and field guides; recording student comments

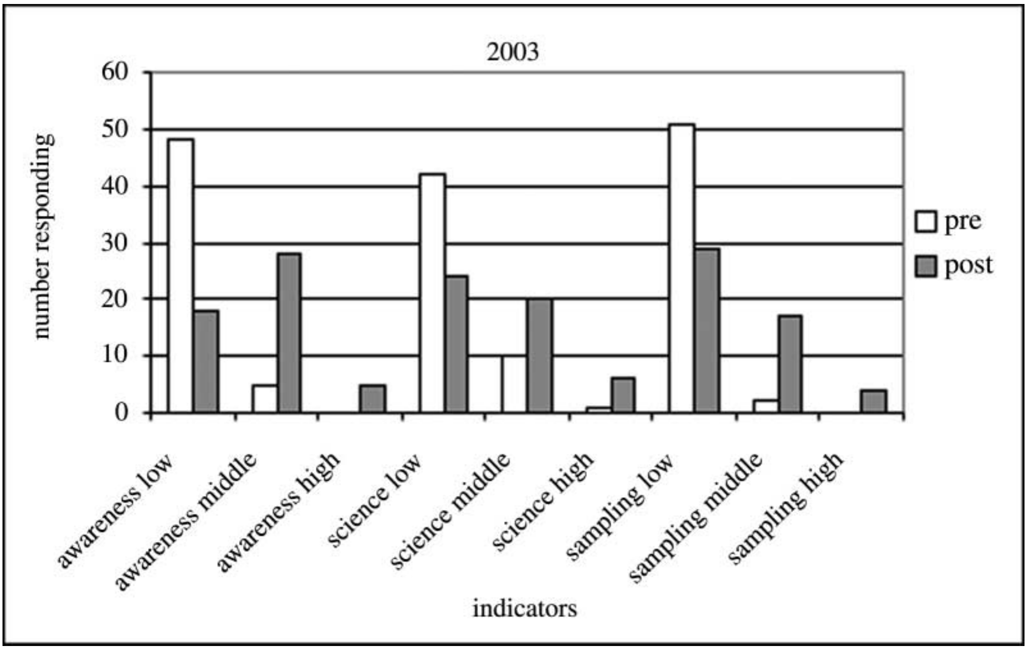

Figure 2(a). Student writing samples from 2003. The samples indicate high, middle, and low goal achievement in awareness of organisms and surroundings, science methodology, and sampling methodology compared pre and post using Chi-square. $N = 51$. Significant pre-post changes in goal accomplishment were indicated in awareness and sampling at $p \leq 0.0001$ and in science methodology at $p = 0.0026$.

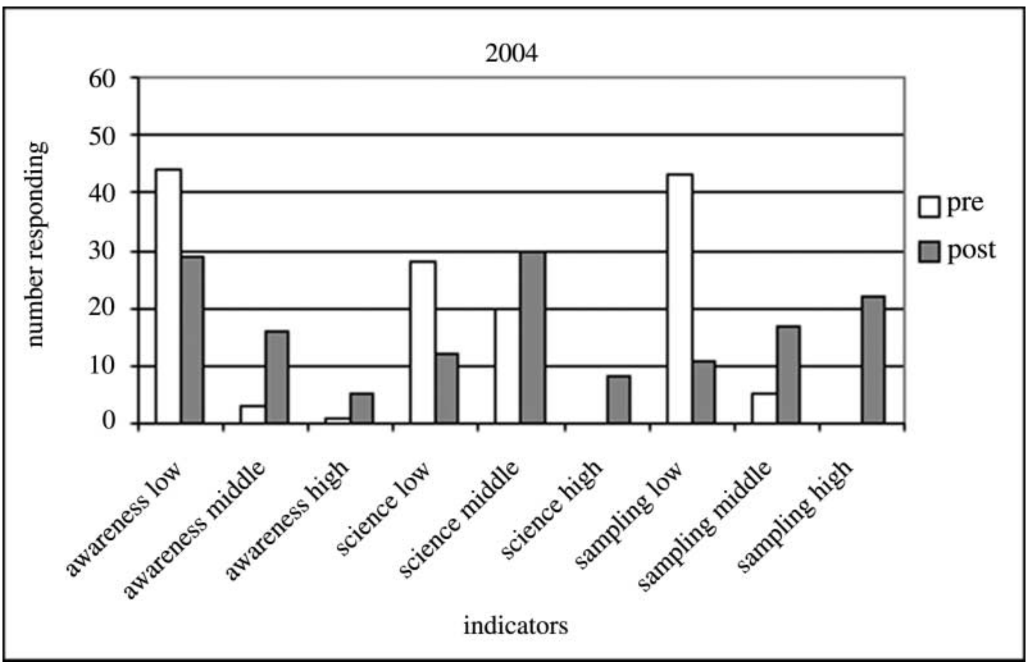

Figure 2(b). Student writing samples from 2004. The samples indicate high, middle, and low goal achievement in awareness of organisms and surroundings, science methodology, and sampling methodology compared pre and post using Chi-square. $N = 48$. Significant pre-post changes in goal accomplishment were indicated in awareness at $p \leq 0.0001$ and in science methodology at $p = 0.0003$.

Table 1(a). Number of concepts listed by students.

Category	Total pooled listings (average per student)
Concepts listed pre-project	198 (4.12)
Concepts listed post-book research	534 (11.36)
Concepts listed post-field research	790 (16.45)
Misconceptions listed pre project	36 (0.75)
Misconceptions listed post-book research	8 (0.17)
Misconceptions listed post-field research	12 (0.25)
Corrections made post-book research	14 (0.29)
Corrections made post-field research	8 (0.17)
Concepts gaining sophistication post-book research	33 (0.69)
Concepts gaining sophistication post-field research	110 (2.29)

Notes: The concepts listed by students ($N = 50$) about specific taxonomic groups pre-project, post-book research, and post-field research, are compared via two-sample paired t-test. Increases in concepts listed pre-project were significant compared to both post-book ($t = 12.80$; $df = 93$; $p \leq 0.0001$) and post-field ($t = 14.00$; $df = 95$; $p \leq 0.0001$) research. Decreases in misconceptions were significant following book research ($t = 4.90$; $df = 93$; $p = 0.0002$), but did not significantly change following field research ($t = 1.09$; $df = 92$; $p = 0.1389$). The number of concepts gaining sophistication increased significantly ($t = 5.02$; $df = 94$; $p \leq 0.0001$) following field research compared to book research.

about the project; and documenting student activities related to participation in the project. For example, students from the 2003 cohort were asked to attend field trips as helpers during the 2004 project. These students were able to work effectively in the field one year after their own projects were completed, and could competently teach the younger students about field techniques and organism identification.

Other examples of positive impacts included unprompted volunteering by students to participate in algal cleanups and as research volunteers at the Hawaii Institute of Marine Biology. After beginning the project, the number of students visiting the classroom to observe, identify and research organisms at lunchtime increased as did the frequency of visits (these lunchtime sessions were not a course requirement). During 2004, some of the previous year's students also made visits when they found out the project had started again. At the end of both years, students had the opportunity to add to a classroom mural of marine organisms. With no guidelines or restrictions, 10% of the 2003 cohort and 33% of the 2004 cohort painted organisms that they had been studying on the mural (an exciting result considering that these paintings included tunicates, sea cucumbers and algae, generally not considered to be the most charismatic or glamorous of marine creatures). Another demonstration of impact happened in 2004. While preparing their final project, students in both class periods who were asked about who might use their field guide answered "other scientists," demonstrating that they were thinking of themselves as scientists.

Table 1(b). Examples of increases in sophistication or misconception correction in individual student lists following independent book and field research of taxonomic groups.

Pre-project	Post-literature research	Post-field research
Sponges are living organisms	Sponges are the most basic multi-cellular organisms (*gain in sophistication*)	
Sponges live in the water	Sponges live in deep deep oceans stuck to rocks (*gain in sophistication*)	Sponges can live anywhere in the ocean, including the intertidal and open ocean (*correcting misconception*)
Anemones have poisonous feelerlike fingers	Cnidarians have a unique feature that are nematocysts that help them catch their prey (*gain in sophistication*)	
Worms are wiggly	Worms are wiggly, but can also be in a tube (*gain in sophistication*)	Sea worms can be bristleworms, flatworms, ribbon worms, and acorn worms. (*gain in sophistication*)
Brittle stars are black and spiny	Not all brittle stars are black and spiny (*correcting misconception*)	Some brittle stars have symbiotic relationships with shrimp (*gain in sophistication*)
Red algae is red	Red algae actually comes in many colors, including red pink, white, black, purple, and brown (*correcting misconception*)	If it is red at the base, it is probably red algae (*gain in sophistication*)

The work of one of the students in the 2003 cohort, 'Karen', provides a powerful example of the value of the OPIHI model. Karen was a member of the crab taxonomic group. Categorised by the school administration as a low-achieving student at the beginning of the school year, Karen informed her teacher early, 'No offence, but I really don't like science'. She maintained a C average during the fall semester, primarily due to late and incomplete work.

Karen's work during the OPIHI project was very different. She consistently completed her work on time and put in extra effort. She spent time in the classroom during her lunch period and before school, identifying and caring for the crabs that her group had collected during field trips. She even came in on a weekend to help sort and identify crabs following one trip when many specimens were collected. We observed Karen participating actively in the class open house, answering questions about her poster and about crabs and the intertidal zone. Suddenly she stopped, turned to her teacher, and stated, 'Wow, I really know a lot about crabs, don't I?' In a reflective piece written for a presentation, Karen said this about her study organisms:

> At first, I was hesitant to learn about crabs. I was scared to touch one fearing it might pinch me (one did, but that's beside the point). It struck me as a surprise that getting to skip classes wasn't the reason I was so excited to go out into the field, not the only reason, anyway. I found myself enjoying going out and finding the crabs and as I learned about them, the more fascinated I became with them. To put in short, I didn't think I'd come back after our first trip with crabs as my second favorite animal. (Author's note: Dolphins are still Karen's favorite animal; it's hard to compete with that.)

Karen's work on OPIHI had a lasting impact and she returned to visit the classroom for the remainder of her high school years in the spring to examine crabs that had been collected by younger students. She also participated in a field trip as a volunteer chaperone and instructed a new crab group about identifying and handling the crustaceans. Karen has not chosen a career in science, but she gained lasting knowledge about invertebrate biology and ecology, and more importantly, she realised that she could do science and use scientific strategies to find out about the world around her.

Contribution to marine science research

During the two years of the project, students identified and recorded over 400 species, including both endemic and invasive species, representing the first such broad scale characterisation of Oahu's intertidal diversity. Students were able to positively identify over 80% of the organisms that they collected and expert confirmation of the accuracy of those identifications was high. Some taxonomic groups, such as crabs, proved more challenging than others to identify, and the majority of organisms the students were not able to identify also required in-depth study by the scientific volunteers to gain a positive identification. Voucher specimens have been entered into the collections at the Bishop Museum. The species-richness data have been presented by the students and the authors at several professional scientific conferences in Hawaii and elsewhere and are in preparation for a paper in the scientific peer-reviewed literature. The involvement of professional scientists in this project increased awareness within the scientific community in Hawaii of the intertidal zone as an important and unique habitat. During the course of this project, three marine resources agencies, which in previous years focused solely on reef habitat, with the assistance of one of us (CJZ), expanded their surveys to include the intertidal zone. These data, along with the project data, have also formed the basis for The Nature Conservancy's ecoregional plan for conservation of intertidal habitats in Hawaii.

The quantitative data first collected by the 2004 cohort, along with data collected using the same techniques by ULS and three other schools in 2005, have been transferred to the National Oceanic and Atmospheric Administration. Again, these data represent the first attempts on record in Hawaii to quantify both algal and animal diversity in the intertidal zone. Our experience collecting these data led to the development of a protocol now being used by twelve schools on four islands in Hawaii as part of an ongoing intertidal monitoring programme. These data are currently being compared with data collected by professional scientists and do not appear to be significantly different from that collected by experienced scientists working on the same transect line as the students (Cox and Philippoff 2008).

Students from both cohorts participated in the presentation of results at scientific conferences. Two students from the 2003 cohort presented their work at an Ecology, Evolution and Conservation Biology seminar at the University of Hawaii and at the 2004 Hawaii International Conference on Education. In 2004, a group of students submitted a proposal to the Hawaii Conservation Conference to present on their documentation of invasive species in Oahu's intertidal zone. Following review by professional scientists, their proposal was accepted to the conference programme and their resulting poster was well-received. This acceptance of the students' work via the same channels used by professional scientists was a powerful confirmation of its scientific value.

Implications for practice

Historically, science courses in the US have focused on series of facts presented in isolation from the process of discovery. This model of teaching misrepresents the nature of science, and does not work in practice for many learners (Young 1997). Inquiry, by contrast, is science taught as a practice, with emphasis upon the suite of thinking skills needed to engage in the process. This approach to instruction requires that students determine how to ask questions, gather information, and assess knowledge (McComas 2004). We used project-based learning as an effective way to conduct scientific inquiry in the fluid and flexible manner needed for students to gain the maximum benefit (Songer et al. 2003).

Barab et al. (2001) describe students in PBL as active learners who engaged in meaningful real-world experiences. Barab and Luehmann (2003) summarise from the work of previous authors (Krajcik et al. 1994; Blumenfeld et al. 1996, 2000) the key components of successful PBL. These are: (1) organising questions answered through long-term investigation; (2) the production of significant, useful artifacts; (3) collaboration with the community including, but not limited to peers; (4) use of cognitive tools to support learning. We sought to target all of these components in our work by building a scientific community in which students worked together with one another and professional scientists to conduct an authentic research project and construct their own knowledge about intertidal organisms and ecology.

What then, is really needed to enable teachers to engage their students in successful project-based experiences? It is often difficult to identify specific elements that contribute to success in teaching. In a survey of 328 third–eighth grade teachers, May (2000) identified a set of 21 'bedrock' elements of teaching practices and competencies that led to successful environmental experiences for students. These included the use of diverse instructional strategies, integration of the curriculum and making curricular connections, experiential teaching, and providing a sense of place. The success of OPIHI has resulted in part from the combination of a set of research-based instructional strategies within the project-based format to allow us to build upon these particular bedrock elements.

Authentic tasks and assessments require student-centered instruction

Edelson (1998) describes the importance of making sure that scientific learning resembles the actual process of science. When the reasoning for conducting the work is clearly part of a scientific research agenda it increases student engagement. The realisation that they are capable of doing science is empowering to students and improves their attitudes about science, while strengthening their ability to do science. Although content knowledge acquired is specific to the project, depth of understanding is increased, as demonstrated by Karen's experience with OPIHI. Teachers, administrators and parents should also be helped to recognise that attitude and empowerment can be a significant value for students, and need to go beyond traditional assessments that do not measure these qualities.

Authentic tasks can and should be used for student assessment in PBL. Had we used tests as a sole assessment of learning, we would not have seen any difference in learning compared to tests from traditionally taught units. By examining student products and observing how students communicated the results of their work in OPIHI, we were able to see how students could correct misconceptions and increase the sophistication of their ideas, synthesise information for public consumption, and prepare proposals acceptable for peer review at a professional conference. Unlike traditional tests, these assessment tools are themselves learning experiences from which students gain skills, experience and confidence. At the same time they demonstrate higher-level thinking by writing about and explaining their work, using synthesis and application thinking skills more advanced than identification and organisation seen on traditional tests. Teachers who are prepared to use multi-dimensional assessment, particularly performance-based tasks, will be more successful in using projects like OPIHI for instruction. Moreover, administrators and teacher educators must empower teachers to employ alternative assessments that capture information about student knowledge missed by standardised tests.

Collaborating with professional scientists and providing students opportunities to work as a scientific community also provide authenticity. Teachers need to become more comfortable with student-centered models of instruction to build a classroom scientific community. Providing legitimate and meaningful opportunities for peer review and time for students to have meaningful discussions with one another are student-centered instructional strategies that can help build classroom scientific communities. Teacher education and professional development programmes that develop practice through professional learning communities can help by modeling the best-practices we want teachers to include in their own classrooms.

The formation of partnerships with professional scientists can benefit not only the students, but also the teacher, and can provide on-site professional development. Such partnerships increase the authenticity of the student experience and provide a model of scientific investigation that can strengthen the teacher's ability to support authentic science in the classroom. It is important that the experience of students be extended beyond the simple data collection of most classroom laboratories to gain an understanding of the complete scientific process (Moss et al. 1998; Gurwick and Krasny 2001). Teachers are more likely to provide a full experience if they themselves understand the scientific process. The gains of the 2004 cohort in understanding about sampling methodology over the 2003 cohort show the importance of providing students opportunities to engage in the full process of investigation. These gains occurred following the first year of the partnership, after the teacher had an opportunity to build her own skills.

Use of project-based learning as a thematic organiser provides time

The time invested in the project provided a solid knowledge base for study in related topics. We did not really spend more time on content that was connected to OPIHI than on other units of study. Required curricular content related to algal biology, invertebrate biology, ecology, and biodiversity was spread through the semester and interspersed with content connected to project framework. Using the intertidal zone as a model system did give all students a solid common ground upon which to build new knowledge. For example, when studying food webs, the class constructed a model web using intertidal organisms. This provided an opportunity to apply the information we had learned about those organisms and provided a perspective in which to frame new information about trophic dynamics. Rather than thinking abstractly about an unfamiliar food web, students applied their real-world knowledge to a broader ecological concept. On course evaluations at the end of the year, many students listed the food web activity as a favorite. We did not see a significant difference between content embedded in OPIHI and traditionally taught content when comparing exams on content taught using both methods, and presumably students did not suffer losses in content knowledge by having course content embedded into OPIHI.

The use of a project as a thematic organiser within the larger curriculum serves a purpose in making authentic environmental study more easily accomplished. In a survey of 45 environmental education teachers from the K-12 level in Kentucky (Meichtry and Harrell 2002), available curriculum was cited by over 70% of the teachers as vital. Thematic connections of the project to the existing curriculum in a constructivist framework make PBL more useful as the project becomes an essential part of teaching, rather than an add-on. When teachers are able to make connections between their current curriculum and a locally-based, authentic project, they can build upon their own available curriculum, rather than using packaged laboratory activities that only provide a piece of the scientific picture and are not relevant to students' experience. This is possible if teachers are provided the time and flexibility to plan ways to connect projects to their selected (or mandated) curriculum. In our case we still had to cover content mandated by the established school curriculum, but the administration allowed us the flexibility to cover the required content by embedding it into the OPIHI project.

Teaching emphasis is on process and students are responsible for content

The biggest challenge to establishing a project like OPIHI is the intimidation factor. The sheer volume of knowledge needed to engage in such a project seems extensive. The project worked because the content knowledge was gathered by the students. Their ability to do so effectively is demonstrated by 2004 cohort data showing students correcting misconceptions and increasing the sophistication of ideas following their self-directed study and the confirmation of their organism identifications by scientific experts. If teachers can be prepared to step back and let students take the lead, PBL is a liberating instructional strategy. It is counterintuitive to traditional teacher professional development because the teacher does not have to be an expert, but rather can learn alongside the students. In this way, teachers can also model the process of scientific inquiry. True scientific investigations are conducted to answer questions and tend to generate even more questions. This is in contrast to most experiments carried out in classrooms, which are usually for the purpose of demonstrating already known facts and concepts, and thus have ‘correct’ answers and pre-determined outcomes.

Our model requires a departure from traditional professional development for teachers in that it emphasises scientific practice more than content. Traditionally, secondary science teachers have been required to focus on the content rather than the practice of the discipline that they teach. Because the practice of science is a complex endeavor, and not as straightforward as the ‘scientific method’ outlined in traditional textbooks, it can be hard for learners to develop a complete understanding of the nature of science (Bybee 2002). The college survey courses required of most secondary science teachers during their pre-service preparation do not convey the nature of science either. These courses usually cover only the outcomes of the scientific process without clarifying the nature of that process. Pre-service and in-service professional development that provides for the development of a full understanding of the nature and process of scientific investigation is needed. Like their students, teachers of science should be immersed in real research, either in pre-service experiences or through partnerships with scientists, as in OPIHI.

If teachers are comfortable with the process of scientific investigation, they are better able to facilitate their students through that process. Moss et al. (2001) noted that when students aren’t engaged in formulating research questions they may be missing a key component needed to develop understandings about the nature of scientific enterprise, even when engaged in scientific study. In OPIHI, students are directly involved in all steps of the research process, articulating research questions, planning investigations, collecting data, analysing data and preparing products that describe and assess that data. Involving students as much as possible in planning can be a vehicle for the introduction of new concepts and the reinforcement of previously introduced concepts and skills. In OPIHI, for example, students practised reading tide tables after learning about tides to help determine the days and times most appropriate for visits to various sites. Teachers who fully understand the scientific process can provide similar opportunities.

Summary

The constructivist model requires time for students to build knowledge and skills. Programmes like OPIHI are possible if teachers can make the thematic connections between the project and the ongoing curriculum that will allow them to take the time needed for students to really construct lasting knowledge. Teachers who are comfortable with their command of the scientific process can facilitate the gain of content knowledge by their students through scientific investigations and more importantly, empower their students to build scientific thinking skills and solve problems for themselves. Requiring students to develop necessary expertise also provides a division of labor and makes projects more manageable while promoting knowledge ownership.

The need for authentic experiences to develop a true understanding of scientific process includes the context of a local experience that students can then analyse and apply to larger global ideas. Authentic tasks can also be used for assessment. Students form a community of scientists when they share their expert knowledge with one another and with their scientist partners and community members through authentic products. We were fortunate to have access to the intertidal zone, but similar projects could be just as effective in streams, fields or city parks and playgrounds, provided that teachers are provided with professional development in the scientific process, and have the flexibility to connect their curriculum to a project.

Acknowledgements

This work was supported in part by the National Science Foundation Graduate Fellowships in K-12 Education programme and by a grant from the Hawaii Community Foundation. We would like to thank former principal Jane Burke of the University Laboratory School for her support, and the students and staff from the University of Hawaii and Bernice P. Bishop Museum who assisted with field trip support and species identifications.

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Appendix. Listing of individual concepts included in the concept inventory and associated statistical values for pooled 2003 and 2004 cohorts ($n = 104$). Concepts marked with * were not targeted in instruction and used to validate student self-reports.

Concept	Pre-mean	Post-mean	Mean shift	*t* Stat	*df*	*p* value
Abiotic	1.22	2.45	1.23	9.99	206	<0.0001
Abundance	3.30	4.03	0.72	4.28	206	<0.0001
Algae	3.44	4.35	0.91	7.34	206	<0.0001
Benthic	1.26	1.91	0.66	5.43	206	<0.0001
Biotic	1.56	2.77	1.21	8.81	206	<0.0001
Carnivore	4.37	4.87	0.50	4.96	206	<0.0001
Commensalism	1.23	4.40	3.16	29.89	206	<0.0001
Community	4.33	4.52	0.19	1.78	206	0.038
Competiton	4.44	4.68	0.24	2.30	206	0.011
Cryptic*	2.20	2.39	0.19	1.19	206	0.12
Dessication	1.34	2.12	0.77	6.24	206	<0.0001
Detritivore	1.25	4.23	2.99	26.11	206	<0.0001
Distribution	4.06	4.07	0.01	0.09	206	0.46
Endemic	2.11	4.03	1.91	10.85	206	<0.0001
Family	4.62	4.49	–0.13	–1.38	206	0.08
Filter Feeder	2.75	4.32	1.57	10.39	206	<0.0001
Fouling	1.94	2.54	0.60	3.85	206	<0.0001
Genus	2.08	3.98	1.90	12.48	206	<0.0001
Herbivore	4.16	4.81	0.65	5.19	206	<0.0001
Intertidal	1.94	4.79	2.84	24.44	206	<0.0001
Introduced	3.92	4.54	0.62	4.40	206	<0.0001
Invertebrate	3.8	4.46	0.66	4.66	206	<0.0001
Larva*	3.85	4.02	0.17	1.29	206	0.09
Mangrove	2.07	2.81	0.74	1.65	206	<0.0001
Metamorphosis*	3.33	3.48	0.15	0.90	206	0.18

Appendix. ***(Continued).***

Concept	Pre-mean	Post-mean	Mean shift	*t* Stat	*df*	*p* value
Mutualism	2.28	4.37	2.09	13.46	206	<0.0001
Native	4.06	4.60	0.54	4.73	206	<0.0001
Parasitism	2.61	4.61	2.00	7.00	206	<0.0001
Population	4.49	4.64	0.15	1.57	206	0.06
Predation	2.11	4.43	2.32	14.79	206	<0.0001
Quadrat	1.64	4.36	2.72	20.11	206	<0.0001
Salinity	2.01	3.65	1.64	8.95	206	<0.0001
Sampling	3.36	4.18	0.82	5.20	206	<0.0001
Sessile	1.2	2.39	1.18	8.80	206	<0.0001
Species	4.09	4.46	0.37	3.12	206	0.001
Species diversity	2.95	3.74	0.795	4.95	206	<0.0001
Species richness	2.31	3.21	0.899	5.46	206	<0.0001
Splash zone	2.22	3.97	1.75	11.01	206	<0.0001
Survey	4.08	4.33	0.25	1.93	206	0.028
Symbiosis	1.93	4.51	2.58	18.25	206	<0.0001
Territorial	3.51	4.01	0.50	3.30	206	<0.0001
Tide	3.99	4.52	0.53	4.76	206	<0.0001
Tidepool	3.95	4.57	0.62	5.31	206	<0.0001
Toxic*	3.91	4.23	0.31	2.14	206	0.01
Transect	1.89	4.28	2.39	17.52	206	<0.0001
Vertebrate	3.61	4.43	0.82	5.76	206	<0.0001
Wave stress	1.82	3.13	1.31	8.13	206	<0.0001
Zonation	1.43	2.95	1.52	10.16	206	<0.0001