DEVELOPING AN INQUIRY-BASED PHYSICAL SCIENCE COURSE FOR PRESERVICE ELEMENTARY TEACHERS

Abstract. Preservice elementary teachers should experience science through inquiry in order to effectively teach science. In addition, inquiry as a mode of teaching is mandated by Kansas and National Science Education Standards. As a result of the No Child Left Behind Act, teachers must also be prepared to teach basic skills in reading and mathematics in all instruction. To address these issues, Fort Hays State University (FHSU) adapted and extended the NSF-developed teacher enhancement materials *Operation Primary Physical Science* (OPPS) for use in a physical science course for preservice elementary teachers. This paper presents main features of OPPS, describes advantages of using it as a template in developing desired course material, and discusses results collected with students enrolled in the adapted course during 2004/2005 academic year.

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Introduction

Experience at Fort Hays State University (FHSU) (P.E. Adams *et al.*, 1999) and elsewhere indicates preservice elementary teachers are not adequately prepared to teach science as an inquiry process nor to integrate basic skills in reading and mathematics in all instruction as mandated by the *National Science Education Standards* (National Research Council, 1996) and the No Child Left Behind Act. Most learning by preservice teachers in general education coursework such as physical science occurs through lecture, while research has shown that few students learn best in lecture-format classes. (Hake, 1997) Although direct instruction has its place in effective learning (Tweed, 2004), extensive research supports hands-on, activity-based learning while preparing teachers to teach science and encourages breaking from the lecture format as the sole means of science instruction. (P. E. Adams & Krockover, 1997; Tobin *et al.*, 1994; van Driel J. H. *et al.*, 1998) Research suggests incorporating group work (Lord, 2001) and graphic organizers, implementing the learning cycle model (Marek & Methven, 1991), and using activity-based lessons. Teachers who experience hands-on learning are more inclined to incorporate these strategies in their own classrooms on a regular basis. (Rodrigue & Tingle, 1994) Based on these findings, a physical science course targeted primarily for preservice K-8 teachers at FHSU was developed and implemented. In this course we followed the workshop format previously developed and tested as *Operation Primary Physical Science* (OPPS), also through an NSF-funded effort (National Academy of Sciences, 2005).

Goals and Research Questions

The overarching goal of this project was to improve preparation of prospective K-8 teachers with respect to content and process knowledge of the physical sciences, as well as to improve their pedagogical content knowledge related to teaching science. A missing component identified for achievement of this goal was preservice teachers' lack of experience with exemplary content/pedagogical models starting with foundation courses. Therefore the key college science course for prospective K-8 teachers (Physical Science) was modified to utilize teaching strategies that have been shown successful in learning science at the elementary level. For this purpose *Operation Primary Physical Science* (OPPS) (Louisiana State University, 2005), an exemplary teacher enhancement project (National Academy of Sciences, 2005), was adapted and extended. This material was developed at Louisiana State University under the leadership of Gayle Kirwin. OPPS is closely aligned with the National Science Education Standards and consists of nearly a dozen modules. Modules are organized by topics and content is concentrated on real-world situations as authentic learning contexts. The OPPS utilizes a five-step variation of learning cycle model (Marek & Methven, 1991) with the following elements:

- Elicit - identify students' prior knowledge,
- Explore – allow for and provide experiences to challenge their prior knowledge and mentally prepare them to learn new material,
- Inquire - expand student knowledge with directed and self-directed investigations,
- Reflect - reach closure on what has been learned, and
- Assess - determine if students have acquired mastery of the concepts being studied.

Through these steps, the model uses and promotes cooperative learning and peer instruction.

Fort Hays State University, among others, was a field test site 1996 – 2001 for OPPS materials. The materials proved effective in developing teachers' knowledge of science and pedagogical content knowledge. Experience also revealed areas where improvements could be made for application of the materials in a college setting. Researchers realized the need to place more emphasis on mathematics, link materials with Mathematics Standards, and make the "big picture" of the content more visible during the course of study. For this purpose, readings from standard texts and various reading strategies (Barton & Jordan, 2001) were integrated into the modified course. Some activities in the modified Physical Science course were replaced with activities that utilized computer-based technology rather than "string-and-sticky-tape" type of investigations. We also developed additional activities to address the limited emphasis on the earth and space sciences in OPPS.

Two main research questions during the course implementation were: (1) Do the preservice teachers' learn content in this modified course? and, (2) What are the preservice teachers' attitudes toward the modified teaching setting?

METHODOLOGY

After adaptation, selection, and refinement of OPPS materials in summer of 2004, the modified Physical Science course was offered during Fall 2004 (F04) and Spring 2005 (S05). Based on results and experience in this deployment phase, materials were modified into their final form and tested during Fall 2005. Achievement of project goals was monitored and assessed through content knowledge gains to address research question 1. To address research question 2, related to student attitudes, several instruments were used. Focus group interviews were used to elicit students' feedback and general impressions. The Colorado Learning Attitudes about Science

Survey (CLASS) (W. K. Adams *et al.*, 2004) served to elicit students attitudes about learning science. Finally the Constructivist Learning Environment Survey (CLES) (Taylor *et al.*, 1994) gauged students' perceptions of the learning environment i.e. its alignment with constructivist learning paradigm. The same instructor was teaching the modified course in all three semesters (F04, S05, F05) while study was conducted.

Although our research questions were focused on performance of the modified course alone, we contended that comparison of the modified course with a lecture-based course could be rather informative as well. Therefore, as a reference point, we administered both CLASS and CLES surveys to students enrolled in physical science course delivered in traditional, lecture-based method. The lecture-based course was targeted toward nonscience majors in general. Both courses were offered at FHSU by two different instructors who taught their respective courses all three semesters during the study. The lecture-based course was taught by an experienced and popular instructor who has been teaching this course in this format for years. The modified inquiry-based course was taught by a new faculty member, a recent PhD graduate, who taught the course for the first time in F04 when study had begun.

Findings and Discussion

Pre- and Post- Instruction Testing

Learning gains in content knowledge were measured for each module through pre- and post-instruction tests earlier developed by the authors of OPPS. These tests target conceptual knowledge and simple experimental design ability. Normalized gain is the percentage gain achieved divided by the total possible percentage gain or: Normalized Gain = (post-test% - pre-test%) / (100% - pre-test%). Hake (Hake, 1997) argues that a normalized gain is an accurate measure of the effectiveness (or non-effectiveness) of a particular presentation style. Learning gains are shown in Figure 1 (where N represents number of students).

All pre/post gains in test scores shown in Figure 1 are significant at the .01 level on a two–tailed t-test. In Figure 1, an outlier was eliminated from one module but gains are significant at the same level even with this data point included. This outlier was removed because it gives a false impression of the gain and the St. Dev. associated with the respective module. This finding indicates that we can positively answer our first research question i.e. students do learn content in the modified course.

Focus Group Interviews

Focus group interviews were used as one of the three instruments used to gauge different aspects of students' attitudes toward the modified teaching setting. Focus group interviews were conducted at the middle and end of each semester. Results varied between these points in that students' comments were more positive at the end of each semester than in the middle. A difference also existed between the semesters; F04 and F05 were more positive than S05 and this difference will be discussed in more detail later. Students in all semesters spoke positively about the class methodology, opportunities for experimentation, group learning, and the support they received during activities from the instructor and TAs. Students welcomed technology and considered it helpful for learning and interaction (e.g., Classroom Response System, DVD demos, animated PowerPoint, and CBL-probeware). They also indicated that peer learning occurred in the classroom. Students' concerns consisted of the timing for activities (either too long or too short), level of scaffolding during activities (sometimes perceived as insufficient - especially at the beginning of inquiry activities), the relatively small number of modules covered and the lack of frequent use of the textbook. They requested improved coordination between the class, the lab and the textbook.

In all the semesters, students were reserved at the beginning and with the exception of a few outgoing personalities, most students were reluctant to participate in discussions and presentations of results. In F04 and F05 students as a group were past this point by the middle of semester and they indicated they enjoyed the course from that point forward. This was not the case in S05 and it was only by the end of the semester that attitudes in general became positive, but again not as much as in other two semesters. Below are several representative comments about the class and the methodology in each of the three semesters:

F04 (mid semester): "We kind of learn what the problem is through the experiment instead of being stated what the problem is.
F04 (mid semester): "… He asks us the question and then we all figure [it] out.… I don't know that he explains stuff. I think he makes us do it."
F04 (end of the semester): It was the first science class I ever really liked!
F04 (end of the semester): I was in here because I'm going to be a teacher. I wish more elementary ed. teachers would take this because we learned in here exactly how they are learning it out there.

S05 (mid semester): "You aren't just given the answers, you have to actually think about it and create experiments and find things out for yourself, and we have to be critical thinkers."
S05 (mid semester): "…it's just kind of fun to do experiments so it keeps everyone involved and I don't know if we take it as serious *[sic]* as we probably should"
S05 (end of the semester): "Yes, I have actually been more excited to learn in this class because it was really hands on …."
S05 (end of the semester): "I think that I learned best when I was able to participate in the group activities. We were able to discuss what experiments we wanted to try and we also had the opportunity to discuss our hypothesis and then eventually figure out if we were correct with our educated guesses."

F05 (mid semester): The advantage [of learning in groups] is you get to express your ideas, it helps you retain the information, it's a lot more enjoyable, it keeps you interested.
F05 (mid semester): And we do stop and talk about stuff that we figured out by looking at our experiments and stuff. We don't just do our experiments, answer the questions, turn them in and leave.
F05 (end of the semester):
Interviewer: What would you keep the same in the course?

- The hands on approach, the group approach, the teacher was amazing,
- Keep the clickers.
- The technology was a lot of fun to play with too.
- Just the open-mindingness *[sic]* to the class, I mean everybody was able to put their opinions in whether they were right or wrong and wasn't a big deal.

Interviewer: Okay, anything else?

- It was a good time.

Results of CLASS Survey

The Colorado Learning Attitudes about Science Survey (CLASS) (W. K. Adams et al., 2004) was used to gauge students' pre- and post instruction attitudes about, and approaches to, learning science. CLASS is designed as Likert scale survey in which students write their agreement to statements such as:

- A significant challenge when learning physics is being able to memorize all the information I need to know.
- After I have answered a question in a physics problem, I examine the answer to see if it makes sense.

This instrument measures changes in terms of favorable and unfavorable shifts in several categories listed in Tables 1 and 2. Desirable changes are positive for favorable changes and negative for unfavorable.

Tables 1 and 2 indicate whether the change in any particular category was favorable or not as well as whether the change in any particular category was significant (as determined by paired two sample t-test for means at 0.05 level).

We will discuss results presented in tables 1 and 2 first by comparing "performance" of the modified course in three different semesters and then by comparing modified course with the traditional one.

Table 1 shows that changes in the modified, inquiry-based course were uniformly desirable during F04 semester with statistically significant shifts in three categories (Overall, Understanding Physics and Personal Interest). In F05 there were no statistically significant shifts but changes were favorable in all but one category. A semester different from these two was S05 when more categories underwent unfavorable than favorable change. While in S05 the shift in Sense Making/Effort category was significantly favorable, overall category shifts that semester were significantly unfavorable. This corresponds to results obtained through focus group interviews in which students expressed quite favorable overall attitudes in F04 and F05 but less favorable in S05.

The traditional course had only two statistically significant shifts (as opposed to five in the modified course), but both of these were favorable (Understanding Physics, F04 and Real World Application, F05). All other changes, desirable or not, were not significant for the lecture-based course, and distribution of favorable and unfavorable changes were much more uniform in this course than in the modified one.

Because the same instructor taught the modified course during all three semesters while using the same course materials and same teaching method, it appears that differences in students' attitudes can be primarily attributed to different "classroom personalities," i.e. to differences in student groups. This presents both a tremendous opportunity for a teacher as well as a possibly dangerous pitfall. Our results also indicate that the inquiry-based teaching setting may be much more susceptible to those variations than course taught in traditional, lecture based format. However it is also possible that the smaller number of students in the modified course could be the reason for greater variations.

Results of CLES Survey

The Constructivist Learning Environment Survey (CLES) (Taylor et al., 1994) was administered to students at the end of the two semesters in the modified course.

CLES is also designed as a Likert scale survey. Typical statements that students reflect on in this survey are:

- I learn that the views of science have changed over time.
- I help the teacher to plan what I'm going to learn.
- I get the chance to talk to other students.

While most constructivists will without doubt consider above statements as favorable, some statements in this survey are aligned only with more radical views of constructivism. For example, in this survey the statement: "I learn that science reveals the secrets of nature" is not considered favorable, although the authors contend that the many moderate constructivists would find it plausible.

Results of this instrument are measured in terms of six categories: The "Personal relevance" scale is evaluates the extent to which students perceive the school science relevant to their out-of-school lives. "Scientific uncertainty" determines students' perceptions of science as a fallible human activity. "Critical voice" describes students' ability to exercise a critical voice about the quality of their learning activities. "Shared control" concerns students' involvement in the management of the classroom learning environment. "Student negotiation" deals with students' mutual interaction for the purpose of building their scientific knowledge. The "Attitude" scale provides a measure of the concurrent validity of the CLES. The attitude scale has been used extensively and has an established reliability (Taylor et al., 1994). CLES was administered only at the end of each semester in the modified course only because lecture courses typically do not address these constructivist goals.

CLES results are shown in the Table 3 in terms of percentages so that 100% would indicate that answers of all students' are in perfect agreement with constructivists views expressed in all statements within the particular category. Results in Table 3 show that modified course classroom in all semesters was perceived as highly (overall, 71.2%) but not exclusively constructivist. This concurs with separate observations of the classroom by one of the other authors (Adams).

As previously stated, 100% indicated that the classroom environment aligned with radical views of constructivism. Thus, the authors considered this result adequate. As a reference point, we also administered the survey in Fall 2005 to students enrolled in physical science course delivered through the traditional lecture format. Results obtained with this sample were unexpected because they were only slightly less constructivist (overall 67.1%) than in the modified, inquiry-based course. Two categories in which inquiry based course "scored" noticeably higher were Critical Voice, Shared Control and Student Negotiation. CLES results indicate that as expected an optimally constructivist teaching setting has been achieved in the modified course. However, in many aspects (in particular Personal Relevance, Scientific Uncertainty and Attitude) these goals seem to be achievable also in a lecture setting.

Conclusions

Students do learn course material in the inquiry-based course developed in this study as shown by significant learning gains for all tests in all semesters. Learning gains and also students' perception of the classroom environment (CLES) did not vary between semesters. Students' overall attitudes toward the class (as found during focus groups) were positive, especially at the end of the each semester. This shows that the methodology was well accepted, but students were typically not initially used to it. It sometimes took more than half of the semester for students to get accustomed to inquiry-based methodology so their attitudes become favorable. Focus group attitudes and students' learning strategies (CLASS survey) were more favorable in F04 and F05 than in S05. Because the same instructor was teaching the course each time with equal attitude and the same content, it seems that non-curricular factors such as students' expectations, interpersonal dynamics and communication skills may considerably affect students attitudes (as shown through focus groups) and approach toward learning in the course (as shown by CLASS). Other possible sources of differences were the size of the group (slightly smaller in F04 and F05 than in S05) and students' comfort with expressing opinions (more outgoing groups in F04 and F05). Finally there is a strong indication that students self-efficacy related to being successful in sciences play a major role in their attitudes toward inquiry based courses. This self-efficacy seems to be a weak link for many, not only preservice elementary school teaching majors (Bleicher & Lindgren, 2005) but for inservice elementary teachers as well (Czemiak & Haney, 1998). Although the modified course was targeted toward preservice elementary school teaching majors, not all of our students were from this population in any of the semesters. Our circumstantial evidence indicates that on average preservice elementary teachers had more difficulties accepting and embracing the inquiry based course than other students. During S05 when attitude results were poorest, the proportion of elementary education majors in class population was largest (more than half). After study was over, in spring of 06, almost all students were preservice elementary majors and in this semester resilience toward inquiry-based teaching was yet greater. However, more specific claims would require a study to specifically target these differences.

Regardless of the class personality, our experience indicates that several strategies can be used at the very beginning of the semester to make an inquiry-based course more interactive and more productive. Because student interaction and engagement play crucial role in this course, it is very helpful to spend first 2-3 classes at the beginning of the semester getting students to know each other and building their teamwork skills through group activities not related to the course content. At this time, it is also necessary to thoroughly describe the methodology and expectations from students.

Overall, this project showed the utility and transferability of excellent teacher enhancement materials (OPPS) to preservice teacher preparation. A possible broader impact of this finding is providing the starting point for similar innovations in other college science courses.

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Table 1.

<u>Comparison of Students' Attitudes about Learning in the modified Physical Science Course Before and After Instruction as per CLASS Survey.</u>

MODIFIED COURSE	Fall 04, N=14			Spring 05, N=20			Fall 05, N=16*		
Category Shift (%)	Favor-able	Unfavor-able	Overall	Favor-able	Unfavor-able	Overall	Favor-able	Unfavor-able	Overall
Overall	1.84	-7.17	Fav*	-6.08	3.11	Unfav*	2.92	1.74	Fav
Understanding Physics	7.14	-13.27	Fav*	-2.33	1.76	Unfav	16.19	0.95	Fav
Math	2.86	-2.86	Fav	5.58	-1.11	Fav	13.33	-5.33	Fav
Sense Making/Effort	0.00	-4.76	Fav	3.46	-2.85	Fav*	-3.33	0.00	Unfav
Real World Application	7.14	-12.50	Fav	-0.72	3.09	Unfav	-1.67	1.67	Fav
Personal Interest	12.50	-17.86	Fav*	-8.75	9.17	Unfav	16.11	-1.67	Fav

Table 2.

Comparison of Students' Attitudes about Learning in the Traditional Physical Science Course Before and After Instruction as per CLASS Survey.

TRADITIONAL LECTURE COURSE	Fall 04, N=42			Spring 05, N=16			Fall 05, N=24		
Category Shift (%)	Favor-able	Unfavor-able	Overall	Favor-able	Unfavor-able	Overall	Favor-able	Unfavor-able	Overall
Overall	1.18	0.97	Fav	2.74	-7.10	Fav	1.07	-1.07	Fav
Understanding Physics	6.35	-3.63	Fav*	2.68	-8.93	Fav	2.38	1.19	Fav
Math	2.14	-3.45	Fav	-1.25	-2.50	Fav	-2.50	0.83	Unfav
Sense Making/Effort	-4.60	4.60	Unfav	-2.08	-1.04	Unfav	-0.69	-4.17	Unfav
Real World Application	5.47	-2.41	Fav	3.13	-9.38	Fav	15.63	-3.13	Fav*

Personal Interest	3.57	-1.79	Fav	-4.69	-10.94	Fav	7.29	-5.21	Fav

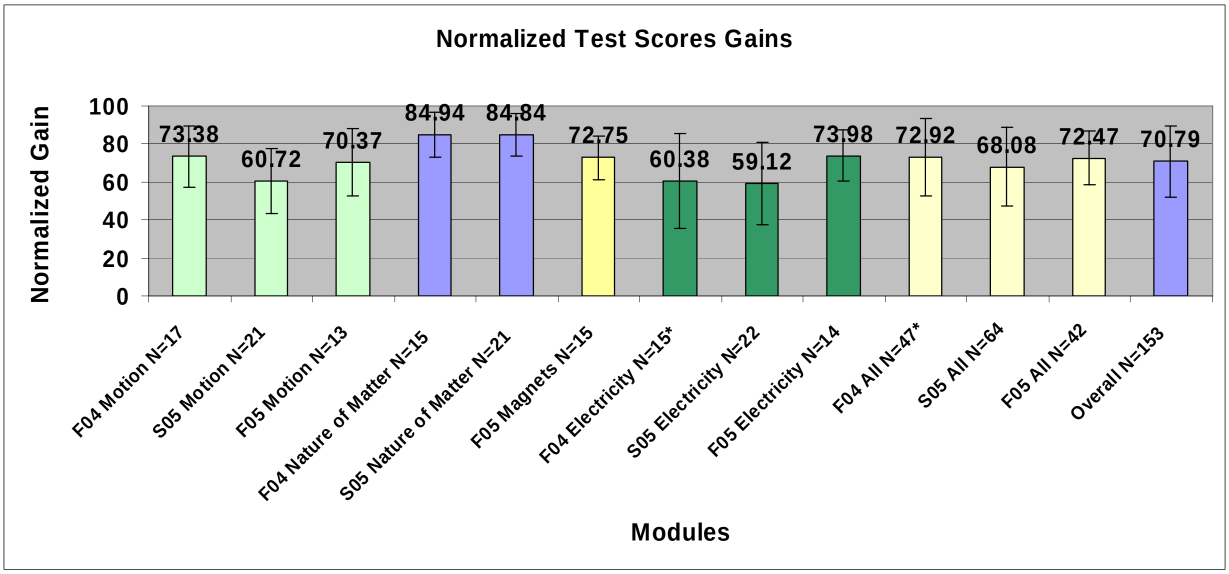
Table 3.

Results from CLES Survey

Scale	Fall 04 (%) (Modified) N=16	Spring 05 (%) (Modified) N=23	Fall 05 (%) (Modified) N=16	All (%) (Modified) N=55	Fall 05 (%) (Tradional) N=94
Personal Relevance	**76.1** +/- 9.6	**74.3** +/- 8.0	**77.0** +/- 11.8	**75.6** +/- 9.6	**76.6** +/- 11.3
Scientific Uncertainty	**67.1** +/- 6.4	**66.3** +/- 8.3	**67.5** +/- 8.4	**66.9** +/- 7.7	**67.4** +/- 7.9
Critical Voice	**78.8** +/- 9.3	**73.0** +/- 11.2	**78.2** +/- 13.3	**76.2** +/- 11.5	**71.5** +/- 12.7
Shared Control	**54.1** +/- 10 .7	**55.8** +/- 14.3	**56.1** +/- 16.4	**55.4** +/- 13.8	**46.8** +/- 13.4
Student Negotiation	**78.9** +/- 9.0	**75.5** +/- 11.8	**81.0** +/- 11.3	**78.1** +/- 11.0	**64.8** +/- 12.4
Attitude	**82.9** +/- 11.0	**71.6** +/- 9.7	**71.7** +/- 13.2	**74.9** +/- 12.1	**75.5** +/- 12.5
Overall	**73.0** +/- 5.9	**69.4** +/- 7.6	**71.9** +/- 8.1	**71.2** +/- 7.3	**67.1** +/- 7.4

Figure Captions

Figure 1. Normalized Content Knowledge Gain Scores for Modules and Semesters.



* One outlying data point eliminated