Implementing and Evaluating Reformed Science Curricula for Higher Education and Professional Development Settings

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Introduction

This paper describes one part of a National Science Foundation Math Science Partnership involving a regional comprehensive university (hereafter known as RCU), several community colleges in the area, many K-12 school districts and two public agencies. The primary goals of the MSP include improving science education across all grade levels through professional development of practicing K-12 teachers, reformed elementary and high school teacher preparation, and substantive change in science content courses at the college level. The North Cascade and Olympic Science Partnership (NCOSP) internal evaluation team, along with members of the NCOSP research group, collected data on the design of the curricula, the implementation of the curricula, and the effects of the implemented curricula on participating undergraduate students and K-12 teachers. While this paper focuses on the implementation of the three curricula and the outcomes for participating undergraduates and teachers, a discussion and presentation of the data on the design phase of the curricula can be found in Landel & Donovan (2007). Specifically, this paper focuses on describing the implementation and reporting the impact of theses inquiry-based science curricula on:

1) Participants' content knowledge in science,

2) Participants' understanding and attitudes about inquiry-based science teaching and learning, and

3) Participants' understanding of their learning process (metacognition).

Research has shown the importance of these two components for both preservice and inservice teachers. Darling-Hammond (2000) and Goldhaber and Brewer (2000) found a relationship between teachers' content knowledge and subsequent student achievement.

Aŕambula-Greenfield and Feldman (1997) found significant gains in inservice elementary teachers' content knowledge and pedagogical content knowledge as a result of inquiry-based professional development. These authors also noted that preservice teachers who learned science in a traditional manner had decreased positive feelings toward science and their own scientific content ability, while inquiry-based science courses increased preservice teachers' positive attitudes and confidence in science. The research highlights the role inquiry-based learning environments have on teachers' content knowledge and beliefs about the utility of inquiry-based approaches for teaching and learning. Current and future teachers need a thorough understanding of the science content they teach, as well as a strong understanding of inquiry-based approaches to the teaching and learning of science, which features prominently in the National Science Education Standards (NRC, 1996). Lastly, Grossman, et al. (1989) highlighted the importance of metacognition, where teachers examine their beliefs about how they come to know science.

Background

The partnership uses a few specialized terms that will be used throughout this paper which should be defined from the start. Teacher Leaders are the approximately 160 K-12 teachers who have participated extensively in the professional development activities provided by the grant. They have participated in three Summer Academy programs and many Learning Community Forums during the academic year. In the last two years of the grant, the role of Teacher Leader has expanded to include the dissemination of professional growth by teacher leaders in their school buildings. A Teacher on Special Assignment (TOSA) is a Teacher Leader who has been selected to work even more closely with higher education faculty and program staff to present professional development at the Learning Community Forums. TOSA's are bought out of their classroom teaching schedule and spend their work day on the university campus.

The Summer Academy events have been two-week residential professional development programs put on at Regional Comprehensive University. Each SA has included approximately 40 hours of content immersion (physics, biology or Earth science) and 40 hours of other professional development. Learning Community Forum or LCF is the term used for professional development meetings that take place during the academic year.

These are presented at a variety of sites around RCU to enable Teacher Leaders to get to them more easily. Each LCF lasts for one day, with the TL's substitutes provided by grant funding.

Table 1:

2005-2006 Preservice Teacher Enrollment				
Content	**Location**	**Quarter**	**Year**	**Enrollment**
Physical Science	CC1	Fall	2005	24
	CC2	Fall	2005	14
	CC3	Fall	2005	26
	RCU	Fall	2005	18
	Total			82
Earth Science	CC1	Winter	2006	18
	CC2	Spring	2006	23
	CC3	Winter	2006	24
	RCU	Winter	2006	23
	CC4	Spring	2006	2 (closed)
	Total			88
Life Science	CC1	Spring	2006	19
	CC2	Winter	2006	21
	CC3	Spring	2006	22
	RCU	Spring	2006	27
	CC4	Summer	2006	24
	Total			113

The three courses (The Flow of Matter and Energy in Physical Systems, The Flow of Matter and Energy in Living Systems, and The Flow of Matter and Energy in Earth Systems) have all been taught at a regional public four-year university and the partner community colleges in the area. All schools operate on a ten-week quarter system, and each course is one quarter long. The classes meet three times each week, in two-hour blocks, for a total of six instructional hours. The courses were capped at 24 students, and the actual number of students ranged from 12 to 24. Faculty generally worked in pairs, team-teaching each course. Students worked in cooperative groups of 3-6, though homework and exams were completed individually. This sequence of courses is the core science requirement for future elementary teachers at WWU, so providing the same course sequence at area community colleges is intended to smooth the transition from the community colleges to RCU's teacher education program.

The majority of students in the courses are in their second year of college level work, though small numbers of junior and senior level students enroll at the four-year institution. The amount of previous science coursework varies widely from one student to the next, though most have little or no previous college-level science experience.

Table 2:

SA Inservice Teacher Enrollment*		
Content	**Year**	**Enrollment**
Physical Science	Summer 2004	170
Life Science	Summer 2005	172
Earth Science	Summer 2006	162

*"Inservice Teacher" includes Teacher Leaders, District Teacher Leaders, Participating Teachers, and TOSAs.

The curriculum materials were also adapted for use with practicing teachers in three Summer Academy events in 2004, 2005, and 2006. The content strand focused on physical science the first year, life science in the second year, and earth science in the third. Teachers worked in groups separated into grade level bands (elementary, middle, and high school) for 40 hours over the two weeks, and completed a portion of the materials designed for the 10-week college courses. Each room of 25 to 40 teachers was led by a team of three to five content facilitators made up of higher education faculty (including a content specialist for that subject area) and at least one Teacher on Special Assignment. The participants worked in groups of three or four, and participated in both small group and whole class discussions with little lecture by the facilitators. In addition to providing subject specific content to the K-12 teachers, a second goal of the Summer Academy sessions was to demonstrate effective science pedagogy to the participants. Content facilitators led focused discussions of specific pedagogical strategies at appropriate times in the sessions, sometimes supplemented with video recordings of student naïve conceptions of the content under consideration.

Structure of the Curriculum

For these curricula, we relied on commonly used experiments and activities but we approached them and linked them together in an unconventional manner. The content cycles are subdivided into activities which all follow a learning cycle. At the beginning of each content cycle and each activity, students are prompted to record their initial ideas about a concept and discuss them as a small group. The ideas from the small groups are then shared with the class using small whiteboards. This allows facilitators to elicit preconceptions and allows all participants to hear the variety of initial ideas. Following this elicitation, the students complete a series of activities designed to specifically confront common misconceptions and to allow students to construct knowledge in a sequential manner. Throughout these activities, students are required to make predictions, gather data, and draw conclusions. At the end of the activities, students are prompted to specifically reconsider ideas held before the activity and to document any change in their thinking. The following sections describe the learning cycle in greater detail and provide examples of what each stage looks like in practice.

Initial Ideas

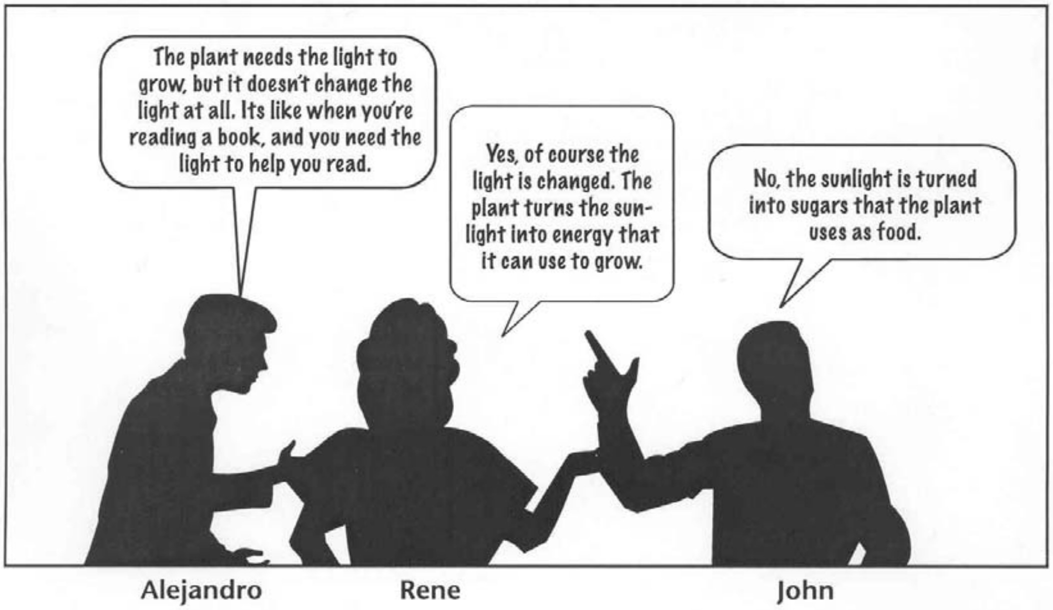
At the start of each cycle, participants are presented with an "initial ideas" question, which asked them to individually write down their answer to an open-ended question. They might then share their answers with their group and the whole class in a group discussion. Groups would then engage in a series of activities addressing the ideas activated by the initial ideas question. In all settings, there is an emphasis on writing down initial ideas and answers to questions along the way, to facilitate later reflection on their own learning process.

One way to get at students' ideas is to present common misconceptions and ask if they agree or disagree with the ideas presented. The following initial ideas conversation happened in the Summer Academy; these participants are high school teachers talking about what happens when light falls on a leaf. Prior to this activity, the participants had explored what "food" is for all living things, and then narrowed that question to "What is food for plants?" They had also looked at where starches are stored in plant materials.

"Al" teaches Earth and general science, "Bob" is a biology teacher, and "Carl" teaches physics. They were provided with the following prompt, which is followed by a transcript of their conversation. The "breaks" in the conversation are where the conversation went off-topic.

EXAMINING STUDENT THINKING

A teacher asks her students how sunlight is used by plants. During the discussion the following student responses are heard:



Which student has the best understanding of the plant's use of sunlight? Explain your reasoning.

GROUP DISCUSSION

Share your ideas with your group.

Figure 1

Al: I'd say Alejandro has the best understanding.

Bob: Why?

Al: Because, well the sunlight isn't turned into sugars.

Bob: John was wrong.

Al: 'The light is changed. The plant turns the sunlight into energy.' It doesn't turn the sunlight into energy.

Bob: 'That it can use to grow,' but what form of energy is that?

Facilitator: OK, where are you-all at?

Bob: We're talking about these three people.

<Break>

Al: I see what you're saying, but I don't think that's right, and I don't necessarily think this is right either.

Bob: Well I don't think either of them is completely right, but I thought Rene was the least not right because...

Al: I don't like that the light is changed, I don't like that statement. [To Carl] What do you think? What did you say, Rene is right?

Carl: All of a sudden I'm thinking that the uh… When you read the paper, when you read the page you've got black on white. All the white is being reflected off. We've got all these different wavelengths coming back at us whereas the black is being absorbed. But we see green on the plant because the green is coming back at us but everything else is being absorbed.

Bob: Being absorbed. So where does it go when it's absorbed does it just like vanish?

Carl: Yeah. It's got to turn into some sort of energy.

<Break>

Bob: OK, so the light. Part of it is reflected. Part of the light coming from the light bulb, or the light source, whatever is being reflected by the leaf, and part of it is being absorbed. And the energy that is being absorbed is being converted into-via some magical process into chemical energy. We don't know how, yet. But …

Al: Right. Yeah. The problem is the words we're using. 'The light has changed.'

Bob: Well, the…

Al: The light isn't changed, it's absorbed. And the light, you, it would be better to say that the plan needs energy from the light to grow, but it doesn't change the energy at all. If you change that then definitely it's wrong but…

Bob: Which of these, the question is 'which student has the best understanding?'

Al: Yes, so Rene.

Bob: So why do you think Alejandro is then wrong?

Al: Well, because of this word 'light' vs. 'energy.' If I replace 'light' with 'energy' then it works. I get hung up on that for some reason, I'm not sure why.

Bob: And I think that the way Alejandro says that the light is just totally passive has no, is just like-

Al: Well it doesn't change the light at all, but I can see what he's saying because it's not-

Bob: Some of that light energy is somehow converted—I didn't say changed—somehow converted into another form of energy.

Al: See it's the language it's my limited understanding and this, the use of this language, so … yeah, OK.

This conversation shows several key features of the implementation of this curriculum for professional development:

1. Teachers with a variety of content-area backgrounds were able to engage with important ideas in the flow of energy in living systems. Note that Carl, the physics teacher, emphasized the absorption and reflection of various wavelengths of light; he made use of his physics content knowledge to help move the group forward.
2. Though all these teachers have undergraduate degrees in science, their mental model of what happens at light falls on a leaf is not fully developed.
3. Responding to the student conceptions and evaluating them elicited these teachers ideas about the process.

The Initial Ideas start to each cycle is followed by a series of hands-on activities described in the next section.

<u>Activities</u>

Having activated students' current conceptions of the topic, a series of activities designed to expose common misconceptions are presented. There may be one or two, or as many as five activities in the cycle. The activities vary in length from one cycle to the next, and use a variety of data collection and analysis tools. In the life science curriculum they include finding the location of starch in green plants, measuring the CO_2 and O_2 produced by plants, and a manipulative model of human digestion. In the Earth science course, activities include explorations of density (and density variation with temperature), heat transfer, and map interpretation.

The following vignette comes from the middle of a jigsaw cooperative learning activity on plate boundaries in the Flow of Matter and Energy in Earth Systems course. Students were initially placed in "plate" groups, named for North and South America, Africa, Eurasia, Australia, and the Pacific. Those plate groups were then re-distributed into "specialty" groups, each with a different data set to examine. In the preceding cycles, students had participated in an activity on the nature of science exploring the differences between observations and inferences, as well as measuring the density of a variety of rocks to explore the concept of isostasy. This jigsaw activity forms the core of the third cycle in the Earth Systems course.

Students are at tables, in groups of three or four, and each group has a large world map with a particular data set. One map has earthquakes plotted world-wide, with the color of the point indicating the depth of the earthquake. Another group has a map where the age of the sea floor is indicated by colored bands (and the continents provide no data.) A third group has the locations of volcanoes plotted around the world, and the last group has a world map with elevation of the sea floor and continents indicated by color gradations. The groups have been given the task to look for interesting, notable patterns in their data, and also to see if any of the patterns in their data correspond to a world map that has tectonic plate boundaries indicated.

Faculty members (there are two for this class) are circulating around the room, pausing to talk with groups and ask questions. One of the instructors approaches the earthquakes group and asks what the students have noticed on their map. Students reply that the earthquakes seem to happen on the edges of continents, and there are some places where the lines of earthquakes are narrow and well defined (the middle of the Atlantic Ocean, for example) and other places where there are earthquakes over a broad area (around the Mediterranean.) The instructor notes that these are useful observations to make, and asks if they have noticed any patterns in the depth of earthquakes anywhere. After a pause of a few seconds, she points to South America on the map and suggests that the group examine that area more closely. After the instructor leaves, members of the group look at the earthquake data along the west coast of South America, and notice that the dots transition from red to green to blue as they get farther from the Pacific Ocean. This change in color indicates that the farther east earthquakes are, the deeper they are in the Earth.

Around the room, the other groups are having similar struggles and triumphs as they examine the data on their maps. The goal is to have a chart filled out with several patterns in their data described, and an explanation of how those patterns correspond to “known” plate boundaries. Then, the groups of data “experts” will break up and students will re-form their “plate” groups, which include students from each of the content specialties.

The instructor frequently asks students if they agree with the placement of the known plate boundaries on the map provided in class. There are several regions around the world that present problems. Some where plate boundaries are indicated but there is very little data supporting the location of the line, and others where there is data that suggests a boundary, but the map does not show one. Students are encouraged to consider the implications for science; when is there enough data to decide if the boundary is 'real?' Should they trust their analysis of the data, or the map handed out by the instructors?

Following this cycle on plate boundaries, students move on to explore the mechanisms that drive plate tectonics and move heat from the core of the Earth to the surface. This includes a return to heat conduction, convection and radiation that were briefly touched on earlier in the course, as well as treatment of energy transfer in earthquakes. The final cycle in the course asks students to synthesize the material into an over-all chart of energy transfers through the Earth's geological systems.

Scientists' Ideas

After students have worked with the new concepts, and hopefully figured most things out through the activities, whole class discussions, and homework, the cycle is wrapped up with a short review section presenting the current scientific consensus on the topic.

Following the activity and homework pages, each cycle concludes with a section titled "Scientists Ideas." This is where a brief summary of current scientific thought on the topic is presented. After struggling with the ideas individually and in groups, the summative nature of these segments helps students to feel more comfortable that they have a grasp of the content.

Homework

The intensity of the summer academy experience (participants were engaged with workshops from 8:30 AM to 4:30 PM) precluded the use of homework in the implementation of these curricula. In the ten-week quarter used by all the higher education partners, homework is an essential part of the courses. (As mentioned above, the classes meet three times per week, in two-hour sessions.)

Typically, homework is designed to re-enforce concepts students explored in the activities. The following homework assignment comes immediately after an activity where students used indicators to detect the presence of carbohydrates, protein and fat in various foods. This assignment asks them to extend their analysis to other foods and draw conclusions based upon the available data. Note that students are explicitly asked to provide the evidence supporting their answers to these questions.

Nutrients in Food I

Using the same chemical tests that you used in the previous experiments, scientists have been able to determine the chemical composition of the foods we eat. The following table lists the composition of several common foods.

TABLE 2-10 **Types of nutrients found in food**

Food	Water (%)	Carbohydrate (%)	Protein (%)	Fat (%)	Vitamins & Minerals (%)
Coca Cola	90	10	0	0	<1
Marshmallow	16	75	9	0	<1
Ground beef, lean	56	0	25	19	<1
Lamb chop	44	0	20	36	<1
Chicken breast	62	0	30	8	<1
Corn	70	26	3	1	<1
Beans, refried	74	19	6	1	<1
Rice, brown	71	26	3	<1	<1
Banana	75	24	1	<1	<1
Peanust, dry roasted	1	22	25	48	<1
steak	54	0	27	18	<1
broccoli	88	8	3	0	<1
twinkie	26	60	2	12	<1
oreo	6	71	3	20	<1
kit-kat bar	3	61	7	29	<1

Based on Table 2-10 do you think is the chemical composition of most plants? What is your evidence?

Based on Table 2-10 do you think is the chemical composition of most animals? What is your evidence?

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Figure 2

Depending on the context and purpose for the homework assignment, it may be graded simply for completion, or may be assessed on the relationship between students' conclusions and the evidence used to support those conclusions.

<u>Metacognition</u>

Research supports the idea that learning is improved when students are asked to explicitly consider their own learning process (Bransford Brown & Cocking, 1999). Thinking about your own thinking, or metacognition, is the final key step in these curricular materials. Sometimes the process of reflection is facilitated through homework questions which ask students to compare their initial ideas to what they think at the end of the cycle.

The Plate Boundaries activity described above also provides a good example of how the Earth Science curriculum materials encourage metacognition in students. Before beginning the jigsaw activity, participants are asked to look at a map of the Earth and to divide the surface into pieces, using some set of criteria. Students present their pieces to the class in a whole class discussion. They then go through the jigsaw activity and investigate the evidence scientists use to divide the Earth into tectonic plates. At the end of the cycle, students are prompted to "Look back at your initial ideas about plate boundaries and plate motions. How has your thinking changed?"

Methods

The data was collected through the ongoing research and evaluation of NCOSP, which utilized a mixed-method approach to the study of the three curricula that includes a quasi-experimental one-group pretest-posttest design to examine the impact of the curricula on the three focal areas, as well as a one-group posttest-only design that includes analyses of surveys, interviews, and participant work at the end of the curricula (Shadish, Cook, & Campbell, 2002). The evaluation of the curricula enacted with students at the five partnering higher education institutions during the 2005-2006 school year included: 1) Content assessments (pretest and posttest), 2) Focus group interviews of students at the end of the courses, and 3) Reviews of student work, specifically, student essays at the end of the courses about their learning, called "Learning Commentaries". In the second year of implementation the Epistemological Beliefs Assessment for Physical Science (EBAPS) was administered to students at the beginning and end of each course to examine the affect the curricula had on students' beliefs about the nature of knowledge and learning in the physical sciences (White, Elby, Frederiksen, & Schwartz, 1999).

The evaluation of the three abbreviated curricula within the two-week Summer Academies included the following data collection efforts targeting inservice teachers: 1) Content assessments (pretest, posttest, and one-year posttest), 2) A survey at the end of the two-week SA professional development, and 3) A survey administered toward the end of the school year following each SA that examined the impact of the previous SA on their teaching practices. Additionally, the evaluation of the SAs included survey and interview data from the higher education faculty and TOSAs who facilitated the implementation of the curricula. In this paper, facilitator interview data is used to corroborate teachers' self-report data where applicable.

Analyses of the data were primarily conducted by the NCOSP internal evaluation team and the external evaluation team at Facets Inc. Instances where analyses were conducted by parties other than the aforementioned are noted in the subsequent sections. Quantitative analyses were conducted through the use of excel or SPSS software, and specific tests conducted are mentioned along with each data set. Qualitative data, in the form of open-ended responses to survey or interview questions, were examined using thematic analyses. Thematic analysis is a process of encoding qualitative information, which can be used with any form of qualitative data (Boyatzis, 1998). Themes were generated through a data-driven "grounded" approach, where the themes emerged from the data through careful analysis (Strauss, and Corbin, 1990).

The content assessments administered to undergraduate students and K-12 teachers are presented in Table 3 below. The PET content assessment was the only test with open-ended questions that required scoring through the application of a rubric. The instructors of the courses scored the pre and post PET assessments. A random sample of posttests (N=36) were also graded by an independent group, the Science and Mathematics Program Improvement (SAMPI) group at Western Michigan University, to determine the reliability of instructors' scoring to the independently scored tests , which was high (r= .87). The Earth Science content assessment contained multiple-choice items that were scored and analyzed by the NCOSP evaluation team in conjunction with the Testing Center at the regional comprehensive university. The HRI Life Science content assessments were scored and analyzed by Horizon Research Inc.

Table 3: The three science courses and corresponding content assessments

Course	**Timeline**	**Assessment**
Physical Science Course: Investigating the Flow of Matter and Energy in Physical Systems	Fall Quarter 2005: Students Summer 2004: K-12 Teachers	A six item assessment for that combines multiple choice items and open-ended responses to explain the reasoning behind your selection.
Earth Science Course: Investigating the Flow of Matter & Energy in Earth Systems	Winter Quarter 2006: Students Summer 2005: K-12 Teachers	Pilot test in winter quarter 2006 contained 25 multiple choice items*. Revised assessment used at SA 2006 contained 22 multiple choice items.
Life Science Course: Investigating the Flow of Matter and Energy in Living Systems	Spring Quarter 2006: Students Summer 2006: K-12 Teachers	22 multiple choice items

*Only 13 questions kept for the final analyses due to validity issues, such as poorly worded questions or questions on concepts that were not covered in the courses.

Results/Findings

The following sections present data that show the impact of the three curricula on undergraduate students and K-12 teachers in the following three areas:

1) Participants' content knowledge in science,

2) Participants' understanding and attitudes about inquiry-based science teaching and learning, and

3) Participants' understanding of their learning process (metacognition).

The data shows statistically significant increases in the content knowledge of undergraduate students and K-12 teachers as a result of their participation in the three inquiry-based science curricula. Additionally, both students and teachers reported increases in their understanding of inquiry-based teaching and learning and their understanding of their own learning process as a result of the three curricula.

Impact of the Curricula on Content Knowledge

Undergraduate Students

Content pretests and posttests were administered to undergraduate students in the three science courses offered at the five partnering higher education institutions. Table 4 below presents the findings for the pre- and post-content assessments based on one-tailed paired samples t-tests. There were statistically significant differences ($p < 0.05$) between undergraduate students' pretest and posttest scores for all three science courses.

Table 4: Findings from content assessments with undergraduate students

Course/Schools	**Pretest Mean (%correct)**	**Posttest Mean (%correct)**	**Gain Score**	**N**
Physical Science RCU, CC1, CC2	23	74*	.66	53
Earth Science RCU, CC1, CC2, CC3	55	73*	.40	92
Life Science RCU, CC1, CC3	43	62*	.33	65

* Denotes statistically significant increase at p <0 .05

Inservice Teachers

Content pretests and posttests were also administered to inservice teachers participating in each NCOSP Summer Academy and analyzed using paired-samples t-tests. Table 5 shows the statistically significant increases from pretest to posttest for teachers as a result of their participation in the three inquiry-based science curricula. On delayed posttests a year after each curricula, teachers had retained a significant amount of their content knowledge they gained from the curricula.

Table 5: Findings from content assessments with inservice teachers

Course/Schools	**Pretest Mean (%correct)**	**Posttest Mean (%correct)**	**One-year Follow-up (%correct)**	**N**
SA 2004: Physical Science	37	87*	58**	50
SA 2005: Life Science	67	84*	78**	165
SA 2006: Earth Science	65	85*	To be administered in	143

			summer 2007	

* Denotes statistically significant increase from pre-test to post-test at p < 0.05
** Denotes statistically significant increase from pre-test to one-year follow-up at p <0.05

Impact of the Curricula on Undergraduate Students' Metacognitive Skills and Understanding and Attitudes of Inquiry-based Science Teaching and Learning

As previously stated, the structure of the Earth Science and Life Science curricula are modeled after the PET curriculum. Student data from our partnering HEIs have shown that the structure of the inquiry-based science curricula helped students develop a more sophisticated view of the nature of knowledge and learning in science. On a paired samples t-test of the EBAPS, students in the PET courses at three of the HEIs showed statistically significant gains in their attitudes toward science over the duration of the ten week courses (p= .016; N=74). The EBAPS is a forced-choice instrument designed to probe students' *epistemologies*, their views about the nature of knowledge and learning in the physical sciences (White, Elby, Frederiksen, & Schwartz, 1999). Each item is scored on a scale of **0** (least sophisticated) to **4** (most sophisticated). A subscale score is simply the average of the students' scores on every item in that subscale.

It is particularly noteworthy that students showed the largest gains in two subscales: the *Structure of scientific knowledge*, which measures students' perceptions about whether scientific knowledge a bunch of weakly connected pieces without much structure and consisting mainly of facts and formulas or a coherent, conceptual, highly-structured, unified whole (p=.029), and the subscale on the *Nature of knowing and learning* that examines if students believe learning science consist mainly of absorbing information versus constructing one's own understanding by (p=.017). We propose that the large increases in these two areas are due to the structure of the curriculum, which focuses on the "big ideas" in physical science and has students working through the material actively, by relating new material to prior experiences, intuitions, and knowledge, and by reflecting upon and monitoring one's understanding. EBAPS data from the Earth Science and Life Science curricula are forthcoming, and includes data comparing students in the new Earth Science curricula to students in a traditional geology lecture/lab course.

Focus group interview data from students in the Earth Science course (N=6) and Life Science course (N=10) at the regional comprehensive university also support the conclusion that the two new curricula help develop students' understanding of the nature of knowledge and learning in science. Students responded to the opened-ended question, "What skills, dispositions (i.e., how you feel about science), or new ways of thinking about science did (the course) help you develop?" Students responded that they developed the belief that they could develop their own representations of science concepts that mirror those in the scientific community through scientific inquiry and investigations. Comments included: "I think, 'Wow – I just figured this out by myself!'" Since professors were facilitators rather than lecturers, students commented that they "had to figure things out on our own". **S**tudents also felt that the inquiry-based approach to teaching and learning in the class, which used a variety of methods including hands-on experiments and extensive group discussions, was a better way to develop students' understanding of science concepts than the pedagogical methods employed in traditional lecture/lab science classes. These approaches made the learning meaningful to them, and students reported that they "remembered" the science concepts in the course better than if the concepts had been presented to them in a lecture-based course. Students benefited from the focus on the big ideas in science. Students commented, "(The course) helped me grasp the larger issue/overall concept rather than focusing on the details.", and "You have a solid, well established idea or foundation to take with you to other learning situations (as a result of the course)." Also one student noted, "Maybe we learn less [content], but it sticks with us longer". These comments are supported by the content assessment data that showed significant gains in content knowledge and retention of the knowledge a year later.

The finding that the new Earth Science and Life Science curricula helped students feel more comfortable about learning science was also supported by reviews of "learning commentaries", which were essays that students completed at the beginning and end of the courses. The learning commentaries asked students to write about "how they felt about learning science". Reviews of the pre- and post- learning commentaries from students in the Earth Science course at Community College 2 (N=15) showed a large shift. On the initial learning commentary only three students felt "very comfortable about learning science", while, at the end of the course, twelve students felt very comfortable about learning science.

Focus group data from the Earth Science and Life Science courses at the regional comprehensive university illustrate the metacognitive benefits to the inquiry-based curriculum where students shared their initial concepts, conducted investigations around the concept, and then reflected on their initial concepts in light of the data they generated through their investigations. On the open-ended question regarding what skills they developed as a result of the course, students in both courses commented that they developed the ability to examine their initial ideas and reflect on their own thinking and ask "Why do I believe this?" As one Earth Science student stated, "I can ask myself, 'Why do I think this?' and realize that I was completely wrong." Similarly, a Life Science student commented, "(The course) makes you question what you already know, your pre-existing thoughts." They highlighted the importance of small and large group discussions in the learning process, in which they shared their conceptions about science concepts and the evidence they had to support their conceptions. "Before these classes (this quarter and last quarter) I would have defined myself as someone who wants to do things by myself and by being an individual learner– but now having been forced to work in a class where small groups is the focus, I know that I learn more when I am in groups and I wish I had learned that earlier in my education so that I could have learned more in my other classes."

Despite the benefits students cited in the focus group interviews of the Earth Science and Life Science courses, several students in the Earth Science course found the inquiry approach to the curricula unsettling. All undergraduate students in the Earth Science course wanted more direction, terminology, and closure within course activities. Some jumped straight to suggestions on how to improve the course, saying "Maybe since we are not supposed to be told the answer, the class could create an outline of what we learned/should have learned". However, a few students warned that this type of synopsis would need to be carefully guided by a professor to avoid reinforcing any lingering misconceptions. Similarly, a few students in the Life Science course believed that they would learn more content through traditional lecture/lab science courses. Comments included, "I would have liked more lecture, I like having the content solidified" and "I'd just like to know what's accepted by the science community".

Students believed that the courses should stick to the inquiry cycle of "Initial ideas, investigations, and reflection". They felt that sometimes this learning cycle process was short-circuited due to time constraints. Additionally, students wanted more time at the end of each activity to "tie it all together" and synthesize what they had learned. This does not imply that instructors should provide a summary for students at the conclusion of each activity about what students should have learned, rather it involves giving students time to discuss as a group the main things they learned from the activity. As one participant commented, "It would be nice to have five minutes at the end of class for recapping the learning points".

Impact of the curricula on K-12 teachers' metacognitive skills and understanding and attitudes about inquiry-based science teaching and learning

The two-week professional developments for inservice teachers in Physical Science (Summer Academy 2004), Life Science (Summer Academy 2005), and Earth Science (Summer Academy 2006) increased K-12 teachers' metacognitive skills and their understanding of inquiry-based science teaching and learning. These teachers enjoyed the curricula and felt that they gained new science knowledge, which was supported by the content assessment data. Additionally, teachers reported changes in their teaching practices on surveys administered six months into the school year.

On surveys at the end of each Summer Academy (SA), teachers responded to "retrospective" questions that had them rate their understanding "Before the SA" and "After the SA" in a number of areas on a four-point Likert scale from "Very Unclear" to "Very Clear". Table 6 below presents the percentage of teachers who reported having a "Clear" or "Very Clear" understanding to the prompts that targeted inquiry-based science ("How to elicit students' thinking" and "How to help students construct their understandings"), pedagogical content knowledge ("How students learn science"), and metacognition ("My own learning process").

The data shows some interesting trends. There was a significant increase in the percentage of teachers with a clear understanding of the four topics at the end of each SA. This demonstrates that each SA helped increase teachers' understanding in the four areas. Additionally, there was a significant increase over the three SAs in the percentage of teachers beginning the SA with a clear understanding in the four topical areas. This trend illustrates that teachers' understanding continued to increase over time with each SA.

Table 6: End of Summer Academy Survey to Teachers

Rate your understanding of the topics below both BEFORE and AFTER your Summer Academy (SA) experience.	% Clear to Very Clear Understanding					
	SA 2004 (N=144) Before/After		SA 2005 (N=152) Before/After		SA 2006 (N=130) Before/After	
How to elicit students' thinking	46	90	68	92	70	98
How to help students construct their understandings	49	91	60	90	66	96
How **students** learn science	59	95	79	98	81	99
My own learning process	72	98	87	99	90	100

Interviews of higher education faculty members and TOSAs who facilitated the content immersion experiences during the SAs corroborate teachers' self-reports of their increased knowledge and skills with inquiry-based teaching and learning. For example, toward the end of the 2006 SA, five facilitators were asked, "What evidence of learning or growth have you seen in the teacher participants in your group?" Facilitators cited increases in teachers' content knowledge of Earth Science concepts, where teachers used vocabulary appropriately in discussions and made connections between related concepts. Facilitators also reported growth in teachers' understanding of the nature of science. Facilitators commented that teachers learned that science is not about contrived, controlled experiments, and "science exists outside of a test-tube". As one facilitator concluded, "Teachers gained a much deeper understanding of the collaborative nature of science. They were given a huge amount of data and were able to process it and eventually make sense out of it. They saw that they needed each other during the scientific process and I think they can transfer this team approach back to the classroom." Facilitators noted that teachers' discussions about how they might apply what they were learning to their classrooms and ways to make the content more accessible to K-12 students illustrate their deep understanding of the content and pedagogy.

K-12 teachers highlighted the important role the structure of the curricula had on their learning. For example, on the survey after the 2005 SA in Life Science, 29% of teachers commented about the importance of hands-on investigations (N=42) and 36% mentioned the importance of small and large group discussions (N=52), which allowed them to hear others' ideas and challenge their own thinking/understanding. As one teacher wrote, "Activities followed by discussions were most effective for me because the hands-on experience prompted questions or insights that could then be answered/clarified/shared with the whole group during discussion time."

Impact of the SA experiences on teaching practices

Each March, the K-12 teachers who attended the previous SA were sent an online survey to determine the impact of the SA on their thinking about science and their teaching practices during the school year. The response rates were low, approximately 41% on the 2004 SA Impact Survey (N=61) and 52% on the 2005 SA Impact Survey (N=88). Yet, 98% of teachers who responded in both years indicated positive lasting effects from their 2004 and 2005 SA experiences. And 87% and 89% of teachers responded that they felt more confident to teach science as a result of their 2004 and 2005 SA experiences, respectively. The 2006 SA Impact Survey will be administered in spring 2007.

The findings for the 2004 and 2005 SA Impact Surveys were similar across years. Teachers appreciated the opportunity during the SAs to interact with the content and inquiry-based pedagogy from the role of a learner. Teachers felt that this experience as a learner helped them internalize the importance of addressing preconceptions and misconceptions. As one teacher commented, "I experienced first-hand the difficulty of overcoming the misconceptions of oneself and others, and really appreciated the need to draw them out before trying to teach new content". Teachers reported that this deeper understanding of the importance of addressing preconceptions resulted in changes in their teaching practices. For example, on the first SA Impact Survey, 84% of respondents indicated that they had been working to identify and address student pre-and misconceptions in their classrooms. One teacher commented, "The most powerful learning piece that I took away from the summer academy was the need for me to address preconceptions. Now, before I teach a lesson, in any content area, I explore what my students believe before I do anything else." After each of the first two SAs, teachers incorporated instructional techniques into their science classrooms, such as "whiteboarding" and "notebooking" to access students' preconceptions and misconceptions. Additionally, 72% of respondents after the first SA indicated that they had made a conscious effort to increase discussion and dialogue through questioning strategies that helped reveal students' thinking. Similarly, a teacher summed up this notion on 2005 SA Impact Survey by stating, "What was most powerful (aspect of the SA) was the experience of learning by doing and through discussion, rather than by reading or being told. I liked being able to feel what my students would feel and experience if I were to use similar teaching strategies".

Teachers were asked to report any effects on student learning due to changes in their teaching practices. Teachers cited increases in students' engagement in science. Comments included: "The students are more interested, wanting more, and telling me that science is fun, and would like to try other things". Teachers also noted increases in students' understanding of science. When asked on the 2005 SA Impact Survey to provide "evidence" of the positive effects on students' learning due to changes in their classroom practices, approximately 58% of teachers cited "quasi" evidence of change (e.g. student behaviors suggesting deeper understanding, better retention, deeper questions on the part of students, etc.), 22% cited "hard" evidence of changes in students' performance (i.e. unit assessment scores, grades, notebook entries, inquiry plans), while 19% of teacher respondents stated they had no evidence or that impacts on students due to changes in their science teaching could not be determined at this time.

For the teachers with "quasi" evidence of change, they cited changes in the ways their students approach a science task; "students seem to be taking the time to solve problems rather than just waiting to get the answer given to them". Teachers noted that having students identify their preconceptions and then reflect on their preconceptions based on evident from their investigations provided students with opportunities to learn science content and address misconceptions, as well as provided teachers with opportunity to assess changes in students' thinking. However, some teachers mentioned the obstacles to this change in their teaching practices. For example, one teacher commented, "Some students are more frustrated with this change than others. Some students do not know where to begin to solve a problem and some jump right in. Seeing this evidence and not letting the frustrations get too high too fast is challenging. It is too easy to want to give the students the answer." Thus, both teachers and students can find changes in pedagogy from didactic approaches to inquiry-based approaches unsettling.

Meanwhile, 22% of teacher respondents cited “hard” evidence of changes in students’ performance (i.e. unit assessment scores, grades, notebook entries, inquiry plans). For example, one teacher wrote, “Students seem to have a better understanding of the science content and are able to make connections within the content easier. The evidence is in the quality of their whiteboard presentations, in the depth of their discussions, and in the improved work on their assessments.” Teachers also commented that introducing science notebooks into their classrooms allowed students to refer back to their notes and “reflect on their thinking”. Notebooks were also a source of evidence where students could “show a deeper understanding of the material”.

Conclusions

We have described the implementation of the two new curricula, The Flow of Matter and Energy in Living Systems and The Flow of Matter and Energy in Earth Systems, in two settings with different populations; in 10-week courses at higher education institutions with undergraduate students who plan on becoming K-8 teachers, and in two-week summer professional developments for inservice K-12 teachers. These two curricula could be adapted to fit schools on the semester system or for use with undergraduate students with majors outside of education.

These two curricula have positive impacts on both K-12 teachers and undergraduate students. The curricula have been successful in developing the content knowledge of these two groups. The curricula focuses on the “big ideas” in science and incorporates a learning cycles that elicits students’ preconceptions, has them conduct investigations and then re-examine their preconceptions in light of their data. The elicitations and reflections are done through small and large group discussions that help students share their understanding and examine their beliefs. This learning cycle process makes the learning meaningful, which supports the retention of the content knowledge. Finally, we showed the positive impact the structure of the curricula has on both undergraduate students’ and K-12 teachers’ understanding of inquiry-based science pedagogy and metacognitive skills.

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