FOSTERING STUDENTS' UNDERSTANDING OF INTERDISCIPLINARY SCIENCE IN A SUMMER SCIENCE CAMP

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In this study, we present the effects of a two-week interdisciplinary science camp for middle school students. The curriculum was developed based upon results from our previous research with a population of students from the same school district, which suggested some specific deficiencies in students' understanding in the areas of size and scale, structure and properties of matter and forces and interactions. We used three different assessment formats to gauge student learning and attitude changes, including a formal written assessment, small-group discussion, and an attitude survey. The results indicate that the camp was beneficial to the students' learning regardless of gender.

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As new fields of science and technology emerge, science instruction and curriculum materials need to change accordingly (Gilbert, De Jong, Justi, Treagust, & Van Driel, 2002, p. 395). Emergent disciplines of science signal the need for more extensive and fundamental changes than traditional reform efforts promote (Hurd, 2002). Most emerging science is interdisciplinary in nature and requires students as well as science teachers to be able to integrate ideas from several topic areas. Recent calls for reform have highlighted the need for changes in the foci and progression of K-12 science, in an integrated, cross-disciplinary fashion. For instance, the American Association for the Advancement of Science's (AAAS) *Benchmarks for Science Literacy*, widely used in the development of state standards and curricula, highlights the importance of helping students understand the interconnectedness of knowledge and the impact of recent developments in science on society (AAAS, 1993). Another example emphasizing the connections between science disciplines is the "physics first" movement, which has been driven by advances in the understanding of the biophysical basis of nature (Lederman, 2001). Introducing emerging science to the classroom requires changes in instruction, assessment and curriculum development. School curricula must begin to emphasize not only the learning of individual topics, but also the connections between them. In addition, assessments must be developed to support such a curriculum.

However, there are many challenges to this integration. While there is wide recognition of the importance of crossing disciplines in instruction, implementation is often limited by teacher knowledge, curriculum design, and formal school structure (Frykholm & Glasson, 2005). Science in American schools tends to be taught with strict divisions between disciplines. As such, concepts that reach across disciplines are taught in a fragmented manner or ignored altogether (Gayford, 2002; Schmidt, McKnight, & Raizen, 1997). Thus, students often have difficulty making the necessary connections between scientific concepts and ideas. For instance, research into students' conceptions of matter revealed that they often have difficulty applying knowledge from one part of the particulate model of matter to another (Renström, Andersson, &

Marton, 1990). In addition, the same student will often use models of different levels to describe different concepts related to the structure and behavior of matter (Harrison & Treagust, 2000). Often, instructional materials do not link new ideas to prior scientific knowledge to build understanding and integrate concepts across topics. Thus, in current curricula, there is a tendency to treat topics in isolation.

Progressive reform calls for integrating mathematics and science education (Flournoy, Cook-Bax, & Harris, 2001). These calls are supported by research, including studies that have shown that integrating mathematics into a middle school science classroom positively affected students' mathematics achievement (Judson & Sawada, 2000). Emergent sciences require linking important topics across disciplines in a holistic manner. For example, the nature of matter is typically considered a core chemistry concept. However, within the context of nanoscience, one emerging field of science, this fundamental concept is crucial for understanding chemical, physical and biological problems. Another example lies within the concept of size and scale, a complex topic crucial to students' understanding of nanoscale phenomena. The concept of scale has been identified in the AAAS Benchmarks for Science Literacy as a common theme interwoven throughout science disciplines, and size and scale concepts are also prevalent in the form of ratios, proportions, and measurement in the National Council of Teachers of Mathematics Standards (AAAS, 1993; NCTM, 2000). Although these concepts are clearly important to both math and science understanding, studies have indicated that students have limited knowledge of the unseen world (Tretter, Jones, Andre, Negishi & Minogue, 2006; Waldron, Sheppard, Spencer, & Batt, 2005; Castellini et al. 2007; Waldron, Spencer, & Batt, 2006). Thus it is important to place more emphasis on size and scale instruction, preferably in an interdisciplinary manner. Teaching science in an interdisciplinary manner helps students develop abstract reasoning skills, and enables the development of strong conceptual connections (Roth & Bowen, 1994).

In addition, typical large-scale and classroom assessments concentrate on low-level understanding such as describing and recalling. These assessments commonly focus on targeted, isolated topics that do not require students to connect newly-learned concepts with previously-learned concepts from other science areas (NRC, 2005; Pellegrino, Chudowsky, & Glaser, 2001). As a result, these assessments make the integration of knowledge difficult and encourage teachers to focus on isolated bodies of knowledge. This ultimately results in compartmentalized knowledge of science concepts. Thus, new assessments must be developed in order to fully capture interdisciplinary connections between key concepts.

In this study, we present our efforts to foster students' knowledge connections through coordinated interdisciplinary instruction in a two-week informal summer science camp. We developed a curriculum to teach prerequisite knowledge for understanding important principles in nanoscience, including size and scale, structure and properties of matter, and forces and interactions. Nanoscience and nanotechnology are highly interdisciplinary fields that incorporate aspects of chemistry, physics, biology and engineering. We chose to pilot this program in an informal setting due to several factors. First, as previously mentioned, the current structure and curriculum in public middle schools is not conducive to inclusion of emergent science topics, or the interdisciplinary instruction required to address them. Although the activities were developed to match middle school math and science standards, classroom constraints would tend to result in fractured learning due to lack of adequate opportunities to draw connections. Second, research has shown that there is a fairly strong correlation between informal science experience and science attitudes in young high-ability students (Joyce & Farenga, 1999). Thus, by providing this learning experience in an informal setting, we hoped to engage and motivate these students in science.

Curriculum

In previous research, we assessed middle school and high school students on a number of topics we deemed critical for understanding nanoscience concepts and phenomena. These topics include the structure, behavior and properties of matter, and size and scale, which are also core concepts in traditional science curricula. We found that, in general, students struggle in many of these areas, including:

- *Size and scale-* Students often have difficulty estimating relative sizes of objects, even those that are familiar to them. They often do not connect the relative sizes of objects with the value for the absolute sizes (e.g., if informed that the width of a hair is 0.1 mm and the length of a bacterium is 100 times smaller, many students will not make the connection that the length of a bacterium is 0.001 mm or 1 μm). Many students mention small macroscopic objects when asked about the smallest thing they can think of (Tretter, Jones, & Minogue, 2006; Waldron et al., 2005; Castellini et al., 2007; Waldron et al., 2006), but recall atoms or microorganisms when prompted.

- *Properties of matter*- When describing the properties of sugar, a majority of the students relied solely on extensive properties. In addition, students were often unaware that the arrangement of atoms gives a substance its properties.
- *Forces and interactions*- In general, students were unaware that dominant forces change with scale. In fact, for the most part, gravity was the only force that students invoke to govern interactions.
- *Structure of matter*- Students often did not maintain the particle model of matter when asked about melting a solid. They rarely believed that the arrangement of particles in a solid was important.

Based on these results, we designed an inquiry-focused, problem-based curriculum for students who had completed grades six through eight. Students engaged in problem-based learning environments develop fuller conceptual understandings than students in traditional environments, and demonstrate more collaborative tendencies (Cobb et al., 1991; Cobb, 2000). Thus, arrangement of social communities within a problem-based learning setting can be instrumental in aiding the formation of student understanding (Marton, 1993; Roth, 1999). Our design focused on the creation of learning communities to foster shared construction of knowledge. The social, inquiry-based activities enabled wide participation by students at a variety of levels, and provided a variety of authentic settings through which individual understanding could be both developed and assessed (Roth, 1999).

The design of the curriculum was based on the following learning goals:

1. Students will explain some of the ways that scientists observe, measure and make predictions about objects in the unseen world (microscopic and sub-microscopic).
2. Students will explain what determines the properties of a substance.
3. Students will define the nanoscale and relate it to the macro-, micro- and atomic scales.
4. Students will represent measurements numerically on the macro-, micro- and atomic scales.

The driving question, “If we can’t see it, how do we know it’s there?” guided the curriculum. In order to answer this question, we developed a curriculum to explain how we can measure, observe, and work with objects that are too small to see.

We structured the curriculum into two strands: observing and measuring. To instruct students on how we can observe the unseen world, part of the curriculum focused on instrumentation and techniques that scientists use to observe microscopic and sub-microscopic objects. The topics covered included amplification of bacteria and visualization through optical and scanning probe microscopes. Students also used indirect detection methods to learn about unseen objects. They worked with minerals and models to gain understanding that properties are derived from the arrangement of atoms. The instruction in this strand was primarily inquiry oriented. The “measure” strand concentrated on students’ conceptions of size and scale. Students gained experience with very large and very small numbers and practiced estimating the relative sizes of objects. They were also introduced to scientific notation and the logarithmic scale. The objects with which students were working in this strand correlated with those that students’ worked with in the “observe” strand. At every opportunity, attempts were made to make connections between these areas of study.

Our design was consistent with principles of learning in an informal setting. Thus, our design strategy involved: structuring the scientific concepts introduced to the students in a methodical manner; embedding social interaction in all aspects of the curriculum to help support student meaning-making; providing multiple interactional experiences with concepts mediated through social supports; and by fostering and cultivating students’ identities within their science interests (Martin, 2004).

We developed two different instruments to measure student learning. A written assessment measured knowledge in a typical school format. A small-group discussion assessed group knowledge gains, and provided an informal, socially-constructed evaluation of student learning gains consistent with the design of the camp. Each assessment evaluated student understanding of the cross-disciplinary strands as well as whether interdisciplinary instruction helped students access individual topics. Both assessment instruments were implemented before and after the science camp. The main purpose of this study is to investigate the impact of interdisciplinary instruction in an informal setting on student learning, attitudes towards science, and motivation. We were also interested in investigating gender differences in how students learn in this setting.

Methods

Participants

The camp was two weeks in duration with four hours of science instruction each day. Thirty students, 11 male and 19 female, participated in the summer camp. The students attended two Midwestern middle schools in a diverse, urban community, where approximately 50% qualify for free or reduced lunch. There were 11 6^{th} graders, 12 7^{th} graders, & 7 8^{th} graders. The ethnic composition of the participants was 17 African Americans, 6 Caucasians, and 7 others, including six bi-racial students and one Hispanic student. Two Caucasian male students dropped out of the camp after one day and one week respectively, and one student did not take the posttest.

Instruments

Our assessment instruments included an attitude survey, a written content test, and videotaped small group discussions. Each assessment was administered before and after the summer camp.

Attitude Survey

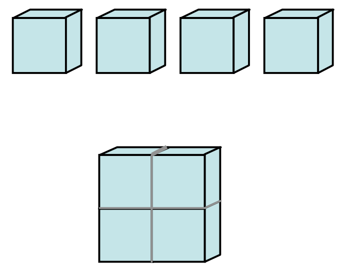
We used a survey developed by Middleton, Blumenfeld, Marx, & Geier (2004) to assess student attitude, motivation, cognitive engagement and classroom perceptions. The survey contained 31 items, each measured with a 5-point Likert-type scale (1 = "Not true at all", 3 = "Somewhat true", 5 = "Very true"). The post-camp survey also contained six open-ended questions that were specific to the activities in the camp.

Written Content Test

We used a written test to assess student content learning (see table 1). The maximum total score of the content test is 35 points. Seventeen multiple choice items counted for a total of 12 points, three short answer items were worth a total of 4 points, and six open-ended questions were worth a total of 19 points.

Table 1
Example test questions

Students were given pictures of two sets of cubes, to answer the following three questions:
Set A- four individual cubes, each with dimensions of 2 x 2 x 2 and Set B- four cubes put together to form a single block with the dimensions 2 x 4 x 4.



Which set of cubes has the largest total volume?

___ A
___ B
___ They are of equal volume.

Which set of cubes has the largest total surface area?

___ A
___ B
___ They have the same surface area.

Which set of ice cubes will melt faster? Explain why.

Small Group Discussion

In addition, students participated in videotaped pre- and post-instruction small group discussions. A member of the research team facilitated each discussion. The discussions followed a protocol focused on: listing objects that are too small to see, grouping them and reaching a consensus on the smallest object(s); the types of instruments that could be used to visualize these objects; and the types of measurement units which could be used to describe the objects.

Data Analysis

There were 27 matched pre-test/post-test pairs for the analysis. One male student was excluded from the analysis because he did not finish the posttest due to a reading and writing disability. A paired-sample t-test was employed to analyze performance and attitude differences between the pre and posttest due to the two weeks of instruction. A Repeated Measures analysis was employed to test for significance of gender differences. The statistical analysis was interpreted to examine the effects of the instruction through overall scores and effect sizes. The students were also assessed in groups of 4 or 5 through a pre-and post-camp small group discussion. One group's data was excluded due to missed collection of the pre-camp discussion video. The discussions were evaluated using a grounded theory approach and through topical analysis.

Results

General results across the full data set are listed in table 2 below. Average results for six undergraduates at a Midwestern research university who took the test for calibration and validity purposes are also included. Scores are broken down by learning goal; performance on each learning goal is discussed below. Results are also broken down by item format, and discussed below.

Table 2
Content Pre and Posttest Results

	Pre Mean (SD) Middle	**Post Mean (SD)** Middle	**College** College (N=6)	**Middle Gain Mean (SD)**	**Middle Effect Size**
Total Score (35)	11.19 (3.26)	15.80 (4.85)	21.92 (1.50)	4.60 (4.20)	1.41***
Multiple Choice (12)	5.62 (1.84)	7.07(2.02)	9.00 (0.55)	1.45 (1.79)	0.79***
Short Answer (4)	1.41 (1.15)	2.44 (1.01)	3.00 (0.89)	1.04 (1.8)	0.90***
Open-Ended (19)	4.17 (1.50)	6.28 (2.74)	9.92 (1.77)	2.11 (2.35)	1.41***
Observe (16)	2.85 (2.65)	5.04 (1.32)	5.50 (1.87)	2.19 (2.84)	0.83***
Model (0.5)	0.31 (0.16)	0.37 (0.14)	0.50 (0.00)	0.06 (0.15)	0.38*
Properties (3)	0.81 (0.61)	1.35 (0.76)	2.75 (0.27)	0.54 (0.78)	0.89***
Size and Scale (15.5)	7.22 (2.46)	9.04 (2.76)	13.17 (1.40)	1.81 (2.69)	0.74**
Size and Measurement (9.5)	4.79 (2.03)	6.56 (1.86)	8.00 (1.18)	1.76 (2.22)	0.87***
Volume and Scaling (5)	2.06 (0.89)	2.15 (1.07)	4.17 (0.75)	0.93 (1.03)	0.10~
Powers of Ten (1)	0.37 (0.49)	0.33 (0.48)	1.00 (0.00)	-0.04 (0.58)	0.08~

Significance values are *** ($p < .001$), ** ($p < .01$), * ($p < .05$), ~ (No Significance).
Effect sizes: 0.0 - 0.4 small, 0.4 - 0.8 moderate, > 0.8 large

Student scores increased by 4.61 points (13%) on the written content assessment, which corresponds to a large effect size of 1.41 ($t = 5.69$, $p < .001$). Students had large effect sizes on all item types, with greatest increases on open-ended items. Since open-ended items tend to measure higher-level cognition than multiple-choice items, the results suggest that students gained not only factual knowledge during the summer camp, but also deeper conceptual understandings. Given the short-term and informal nature of the camp, the gains are satisfactory. To add perspective to these gains, the middle school students' test scores were an average of 51% of the college students' scores on the pretest. In the posttest, the middle school student scores averaged 72% of the college students' average score, indicating that the summer camp curriculum closed nearly half of the gap between the middle school students' scores and the college students' scores (mean = 21.92).

Table 3 below shows results by gender and grade. Male students averaged almost double the gain as compared to females, although the difference is not statistically significant (probably due to the low sample size). Seventh grade students exhibited the greatest gain among students (gain = 17%; $p < 0.05$).

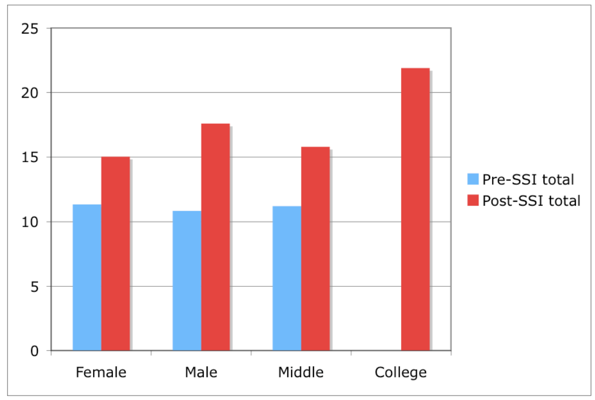
Table 3
Content Pre and Posttest Results

Gender

Gender	N	Gain Score
Male	8	6.75 (19 %)
Female	19	3.70 (11 %)

Grade

Grade	N	Gain Score
6th	9	3.44 (10 %)
7th	12	6.00 (17 %)
8th	6	3.54 (10 %)

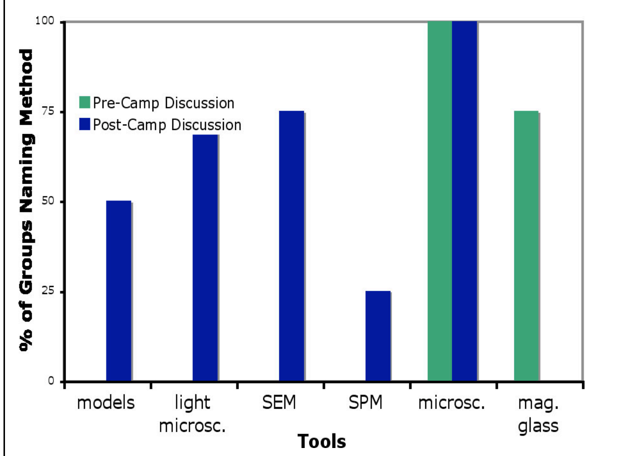


Results by Learning Goals

Learning Goal I: Observe

Learning goal I concerned the tools, models, and methods scientists use to observe, measure, and make predictions about things too small to see with the naked eye. On the written assessment, there were 5 items (16 points total) concerning the tools that scientists use, and 2 items (0.5 points total) concerning modeling. The summer camp achieved this learning goal. Student scores increased significantly on the tools and model items. Analysis of pre- and post-group discussions demonstrated that all groups had expanded knowledge and understanding of the use of tools and models to observe and make predictions about sub-macroscale materials (See table 4).

Table 4
Small-group discussions: Student knowledge of tools used to study things too small to see with the naked eye

<u>Student responses</u> • Models - Students specifically mentioned "models." • Light microsc. - Students specifically named "optical" or "light" microscopes • SEM - Students specifically named "electron" or "electron microscopes," and described their function. • SPM - Students specifically mentioned a "Scanning Probe Microscope." • Microsc. – Students used the term "microscope" without describing the type or function of the microscope. • Mag. glass - Students specified "magnifying glasses."	

Learning Goal II: Properties

Learning Goal II concerned student understanding of the properties of matter. There were two items on the written test that addressed the topic of properties (3 points total).

The summer camp curriculum achieved learning goal II. The students exhibited significant gains in their scores on the properties items.

Learning Goal III & IV: Size and Scale

Learning goals III and IV concerned student understanding about size and scale, particularly related to how students conceptualized and represented things too small to see with the naked eye. There were 17 items on the written assessment concerning size and scale (15.5 points total). The summer camp also achieved these learning goals. The students exhibited significant gains in their scores on the size and scale items. Within the size and scale strand, there were three categories: Size and Measurement, Volume and Scaling, and Powers of Ten. The students made significant gains in the size and measurement category. Through the analysis of group discussions, we found that all groups improved their ability to correctly characterize (list and group by size) objects too small to see with the naked eye, and to identify the smallest object mentioned. In addition, all groups demonstrated an expanded knowledge of micro- and nanoscale measurement (See tables 5 and 6).

Table 5
Small group discussions: Student ability to correctly list / characterize things too small to see with the naked eye

Correct responses
- Object is correctly identified as too small to be seen with the naked eye
- Object is in the best possible size group based on the teams' grouping strategy

Incorrect responses
- Object is large enough to see with the naked eye, or;
- Object is not in the best possible group within on the teams' grouping strategy, or;
- Object is placed in it's own group, without reference to the size of other objects

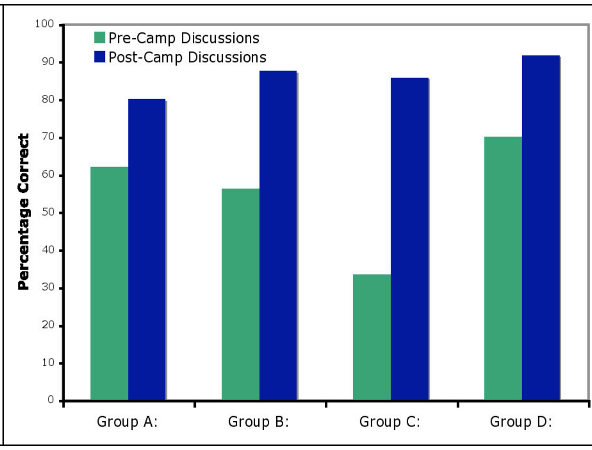
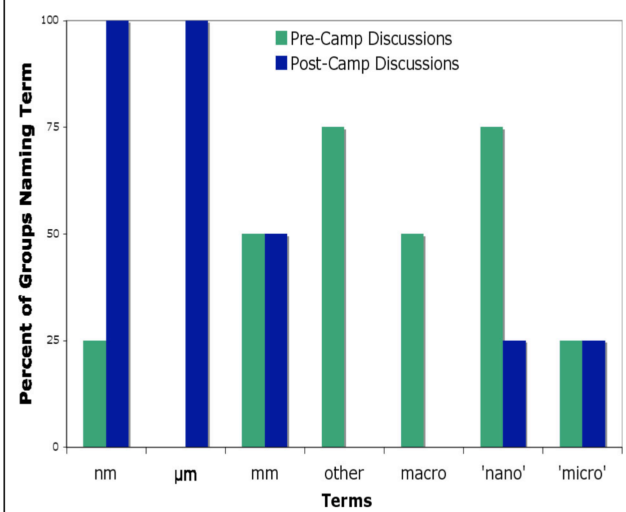


Table 6
Small Group Discussions: Student knowledge of measurement units

Correct responses
- Nanometer-Students specifically used the term nanometer.
- Micron/micrometer - Students specifically used the term nanometer.

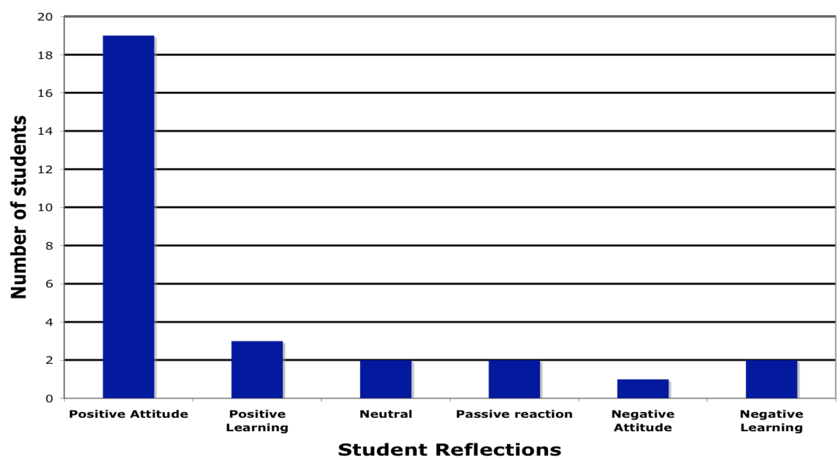
Incorrect/imprecise responses
- Micro: Students said the word micro, without elaborating on the meaning or context.
- Nano: Students said the word nano, without elaborating on the meaning or context
- Milimeter: Students mentioned the term millimeter.
- Other: Students named an ambiguous, or incorrect response which was not macro-scale
- Macro: Students named a macroscopic measurement larger than a millimeter.



In the volume and scaling category, the students significantly increased their score on the open-ended explanation question ($t = 2.68$, $p < .014$), but not on the multiple-choice items. We speculate that the summer camp curriculum improves students' deeper conceptual understanding rather than factual knowledge on volume and scaling. In the summer camp, the volume and scaling instruction was focused on conceptual understanding instead of mathematical calculation. The instructional focus may have influenced the results of the volume and scaling category. Although student scores decreased slightly on the powers of ten category, this category was only assessed using a single multiple-choice item. Analysis of the pattern of answers on this item suggests students may have used a faulty algorithm for calculating decimals from negative powers of ten, inserting one extra zero after the decimal point.

Attitude Results

Our attitude assessment indicated that 22 out of 27 students felt positively about their learning and the experience of the summer camp. Over 90 % (19 out of 21) of 6th and 7th grade students responded that they would like to attend the summer science camp next year. One student responded that she would not return to the camp due to the fact that she is planning to transfer to another school district in the coming school year because of her family's relocation. As motivation and engagement in science class typically fall during middle school, maintaining the interest and energy of a self-selected group of students is a positive and heartening result.



Conclusions and Future Directions

The main purpose of this study was to investigate the effects of interdisciplinary instruction on student learning and motivation in sciences. Based on qualitative and quantitative assessments, the curriculum was beneficial to the students' learning, regardless of gender. We speculate that the intensive, short-term nature of the camp may have reduced the amount of learning detected by the pre and post-tests. Rennie and Johnston (2004) state that, in the context of informal learning in museums, "Learning is change and change is not instant. It requires time for reflection" (p. S7). The full effect of the summer camp experience may only become apparent in students over a longer period of time, and throughout many topics in science and math class.

In the coming year's summer camp assessment, we plan to investigate whether the learning gains are sustained or increased, by evaluating the performance of camp attendees in their school classes and on subsequent standardized tests.

The large increase in male students' scores is encouraging, as urban African American male students generally begin to fall behind on science achievement at this age (Geier et al., *in press*). Students maintained positive attitudes towards science before and after camp. This is a positive sign, as these students are at the age where students tend to lose interest in science (Eccles & Wigfield, 2002). However, the fact that students voluntarily chose to attend a summer science camp suggests that they already have an affinity for science.

This study sample size was relatively small for conducting statistical analyses, yet we found statistically significant effects. However, the generalizability of this study is questionable due to the small sample size. Additionally, the small group discussions and one-on-one interactions between instructors and students revealed greater learning gains than were apparent on the pre- and posttest. This is consistent with findings that indicate that student learning in informal settings is mediated through discussion (Hofstein & Rosenfeld, 1996). In addition, students may not have taken the written assessments seriously because they had no consequences for them and were more reminiscent of the school environment than what they were expecting at a summer camp. Due to these motivational impacts on the test results, we have decided to embed continuous, formative assessment strategies in our instructional activities for the coming year.

In subsequent summer camps, will continue to develop and refine our instructional activities based on our ongoing research and lessons learned in this camp, in order to increase learning and address typical student misconceptions and conceptual challenges. We will refine the curriculum to both drive learning and provide opportunities for assessment during the camp, so both research and educational objectives can be fulfilled. In addition, research indicates that field trips have long-term impacts on learning which are not necessarily immediately realized in terms of student learning gains (Falk & Dierking, 1997; Rennie & Johnston, 2004). Thus, the similarly informal setting of the summer camp may have long-term learning gains. Hence, to adequately assess long-term effects of the camp, we will need to evaluate overall changes in standardized test scores and classroom grades of participants.

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