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Using Summer Programs to Excite Secondary Students about Nanoscale Science and Engineering

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Abstract

Nanoscale Science and Engineering (NSE) is a fast growing area of science and engineering that crosses all discipline boundaries. Several studies have stressed the importance of including nanoscale concepts and topics into the K-12 curriculum. One approach that the National Nanotechnology Infrastructure Network (NNIN) has developed to explore NSE topics with secondary students is through summer programs. At the Georgia Institute of Technology site of the NNIN we offer one week camps to introduce a variety of nanoscale concepts. The Georgia Tech camp provides numerous hands-on activities to explore themes of nanotechnology. Other camps in the network are of shorter duration and focus and include a two-day nanofabrication camp at the University of California Santa Barbara. This camp introduces students to NSE topics and they learn about the science of nanofabrication by building devices in UCSB's teaching cleanroom. This paper describes these two distinctly different camps and their different outcomes which focus on content knowledge for the camp at Georgia Tech and increasing STEM interest for the camp at UCSB.

Introduction

Science, technology, engineering, and mathematics (STEM) education in the United States has been the subject of much attention because of its importance in our economic well-being and quality of life. In *Rising above the Gathering Storm*, it is noted: "Without high-quality knowledge, intensive jobs and innovative enterprises that lead to discovery and new technology, our economy will suffer and our people will face a lower standard of living." [1] Much of this economic prosperity lies upon a STEM-capable workforce yet many indicators demonstrate that our educational system is not producing a scientific-literate population. NAEP 2009 results found that just 34 percent of fourth graders, 30 percent of eighth grades and 21 percent of twelfth graders were rated proficient or higher and more than one in four scored below the basic level [2]. In mathematics (2011), 40 percent of fourth graders and 35 percent of eighth graders scored at or above *Proficient* which is the highest since the assessment began in 1990 [3]. PISA results rank U.S. students 18 in mathematics and 13 in science against thirty-three other countries [4]. There is also great disparity in student readiness for more advanced learning with only 45 percent of U.S. high school graduates in 2011 ready for college mathematics and 30 percent for college science [5].

This poor showing in national and international assessments has increased interest in STEM education in the U.S. including the role informal environments can play in increasing STEM knowledge and interest in our students. Added into this mix of STEM initiatives is the need to include nanoscale science and engineering (NSE) into current STEM learning. Why should NSE be part of this learning? The National Science Foundation (NSF) estimates that by the year 2015 there will be a need for two million workers worldwide in the fields of nanoscience and nanotechnology [6]. Global market estimates for NSE technologies are $1trillion by 2015 and $3 trillion by 2020 [7]. The need for a skilled workforce to meet this challenge has been highlighted in numerous reports [8-10], which stress the critical importance of technological innovation in

U.S. competitiveness, productivity, and economic growth. Nanotechnology is seen as one of these technologically important fields and as noted in *Innovate America,* "nanotechnology could impact the production of virtually every human-made object".[10]

Summer camps are part of informal science learning offerings as the participants choose to enter into the learning environment. Camps represent "free choice learning" in that they are "self-directed, voluntary, and guided by an individual's needs and interests. [11] With the concern about U.S. leadership in STEM, informal learning has become an important arena for promoting STEM interest and literacy. A 2009 report by the National Research Council underscored the importance of learning STEM in informal settings. [12] Other research has shown that positive learning outcomes do occur from informal experiences [13-20, among others]. Education Week highlighted the importance of informal science learning in a short but good overview of various offerings and programs. [21]

We see nano-education as an opportunity to excite students about current science and engineering topics and a way to connect ideas and concepts between scientific disciplines. NSE is considered an interdisciplinary field – one where science and engineering interconnect. NSE provides a platform to demonstrate to students the connections inherent in STEM. The unique properties of the nanoscale can also
be a platform to encourage students to explore science and engineering fields as potential careers. Incorporation of nanoscale topics into the secondary science classroom has been progressing slowly in the past few years. We saw an opportunity to excite students about nanotechnology and STEM by offering summer programs for secondary students.

The National Nanotechnology Infrastructure Network – Education and Outreach Programs

The National Nanotechnology Infrastructure Network (NNIN) is a NSF-funded program which supports nanoscience researchers by providing state-of-the-art facilities, support, and resources. The NNIN is a partnership of 14 U.S. universities (http://www.nnin.org) which provide researcher support. NNIN also has a networked education program which has a variety of offerings for school-age children through adult professionals. Our mission is to address the explosive growth of nanotechnology and its growing need for a skilled workforce and informed public by offering education and training to individuals. We provide resources, programs, and materials to enhance an individual's knowledge of nanotechnology and its application to real-world issues. We believe that a strong U.S. economy requires a STEM-literate workforce ready to meet the technological challenges of a nano-enabled economy as well as an informed citizenry that supports continued and safe growth of nanotechnologies. To encourage STEM and nanotechnology interest, NNIN sites offer summer camps with Georgia Institute of Technology providing week long camps exploring themes of nanotechnology and the University of California Santa Barbara focusing on nano-fabrication. Described below are the two camp models offered by these two institutions. Each approach has different desired outcomes: increasing content knowledge for the camp at Georgia Tech and increasing STEM interest for the camp at UCSB.

Model I - Nanotechnology Explorations Summer Program

Since 2004, Georgia Tech has offered a weeklong camp that first focused on high school students. For several years we provided day activities for middle school students in other camp programs on the Georgia Tech campus. In 2012, we offered the first weeklong middle school summer program. Our camps focus on students in the Metro Atlanta area, are non-residential, and have approximately 24 participants per session. The camps have evolved over time based on participant feedback, presenter observations, and teacher feedback. The Georgia Tech programs use alumni from its Research Experience for Teachers program to teach the camps. This has two benefits – the teachers are veteran classroom science teachers and they have experience in NSE both in terms of research and in teaching.

The initial offering was a combination of faculty lectures, lab tours, and some hands-on activities. The camp was taught by graduate students who were not necessarily doing research in nanoscale science but had an interest in working with students. Faculty were invited to speak on current research topics such as nanoscale materials, carbon nanotubes, and nano-bio applications. Results from the post-camp survey (Table 1) indicated that the participants preferred activities over lectures. This was also stressed in the written comments that included:

- "Less long lectures"
- "Learning real-life applications of nano"
- "Less Power Points and more hands on"
- "Make sure you have plenty of hands-on activities"
- "The speakers were talking in monotome and making everyone sleepy so they should make it more exciting"

Camp 2005 Survey Responses	
Topic	Avg.
Intro to NSE	4.2
Intro to nanoproducts and activity	4.0
Intro to shape memory alloys and activity	4.5
Lecture – nanoscale mechanics	3.3
Mechanical engineering tour and demos	4.4
Lecture – micro/nano-electronics	4.1
Video – Silicon Run Lite	4.0
Activity – circuit board fabrication	4.6
Activity – electrostatic self-assembly	4.1
Lecture – carbon nanotubes	4.4
Activity/tour – carbon nanotubes	4.3
Activity – liquid crystals	4.0
Lecture- materials science	3.6
Activity – materials science	4.5
Lecture – biomedical applications	4.2
Tour - cleanroom	4.4
Lecture – careers in nanotechnology	4.3

Table 1. 2005 camp survey results of topics
Likert scale 1-5 with 1= least favorite and 5= most favorite

In 2006 and 2007, we used the 2005 and 2006 survey results to restructure the summer programs to include more hands-on activities and less lectures by Georgia Tech faculty. The average evaluations for these two summers remained very similar to those of 2005 with the average ranging between 3.0 - 4.5. The written comments included similar responses:

- "Make the camp harder and more challenging"

- "Offer more hands-on activities"
- "Less lecture"
- "Provide more in-depth study of the topic"
- "Hands-on is the best part so do more"

Discussions with the students indicated that they did not want to have talks but rather they wanted to be in the lab doing activities. This seemed counterintuitive in that they needed to have some introductory materials provided to them so that they could understand the nano concepts the activities were focused on.

In 2007, we also added questions to the survey to determine impact in terms of nano perceptions. In particular, we wanted to know if the camp had influenced their self-reported knowledge about nanotechnology, the implications of nanotechnology in society, and if they thought they understood the science of the concepts that were covered during the week.

Camp 2007 & 2008 Survey Responses					
Question about the camp	Very Much	Quite a bit	Some what	Slightly	Not at all
Familiarity w/ nano before camp	5%	0%	41%	30%	22%
Familiarity w/ nano after camp	28%	57%	11%	2%	2%
Helped understand science behind nano	32%	43%	8%	1%	1%
Helped understand how nano relates to real world	31%	49%	8%	1%	1%
Helped to understand how nano applies to your life	32%	43%	19%	2%	2%
Encouraged me to learn more about nano	32%	49%	8%	2%	2%
Made me consider studying nano in college	24%	22%	24%	19%	11%
I understand about nano career opportunities	30%	49%	8%	8%	5%
How likely do you think nano will pose SEI concerns	38%	39%	22%	5%	5%

Table 2. 2007/2008 camp participants survey results- self reported understanding of general nano topics

Table 2 indicates that the students believed that by participating in the camp they had learned quite a bit about what is nanotechnology, the science of nanotechnology, and how nanotechnology relates to the real world. While the results in Table 2 indicated gains in knowledge about NSE concepts, we wanted a more rigorous assessment of student learning. These data were still self-reported and not focused on actual concepts and ideas of NSE and science. In 2008, we did a complete overhaul of the summer camp. We developed a student workbook that provided introductory information on each activity along with a complete description of laboratory procedures. Students also had assigned reading each night related to the next day's topic. The camp was designed to be much more laboratory-focused but still included visits to research labs tied to the day's topic. Each day had its own topic/theme which included: intro/unique properties at the nanoscale; nano and energy; nano and bio/medicine; nano and electronics; and nano and society. We stressed the interconnections between the topics and the science involved in each topic. Our basic premise is that we offer strong science content with a nano-connection. Much of what is taught during the week is tied to science the students have or are learning in their classrooms. For example, when working with ferrofluids students discuss magnetic fields as well as the properties of solutions and colloids. To make the camp more cohesive, we also included a design challenge which students worked on over the week culminating in a final contest to see who had the best working Rube Goldberg device (launching a ping pong ball with nitinol wire as the trigger; it also included information on energy transfers).

With the camp revision, we also developed a new evaluation instrument that continued using the "general" information questions but expanded to include questions pertaining to content knowledge. We wanted to know if camp participants understood the nano concepts and if they had gains in science content knowledge. Figure 1a & b provides examples of the type of content knowledge questions. The instrument was first used in summer camps in rural South Georgia that were associated with a teacher professional development program. This program required the teachers to offer week long summer camps to their students in order to enact the lessons, resources, and knowledge they had obtained in their professional development workshop.

Figure 1a and b. Sample content questions

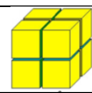
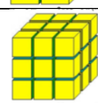
1a. Which has the largest surface area to volume ratio?		1b. How does increasing surface area affect reaction rate?	
A		A	Increases rate
		B	Decreases rate
B		C	Does not affect rate
		D	May increase or decrease depending on other conditions

Table 3 is a summary of the pre and post test results for content learning of the camp participants (n=27). The survey instrument divided the questions into two categories – those focused on nanoscale concepts and those focused on science content. As can be seen, there were gains in content knowledge in both domains but particularly in science content. These data provided our first quantitative evidence that nanotechnology focused activities could enhance student understanding of not only nanoscale science but also science content.

Camp 2009 Pre and Post Content Results n= 27					
Domain	# Items	Mean Score		Change	%Actual/
		Pre	Post	(Pre-Post)	Potential
Nanometer scale	12	39.5	62.0	22.5	37.2
Science content	13	37.9	84.4	46.5	74.8
All topics	25	38.7	73.6	34.9	57.0

Table 3. Summary of content learning pre and post tests of 2009 rural Georgia camps

In 2012, Georgia Tech offered both a high school camp and a middle school camp. Tables 4 and 5 summarize the content learning for middle and high school participants.

Domain	# Items	Mean Score		Change	% Correct	
		Pre	Post	Pre-Post	Pre	Post
Nanometer scale	31	6.20	14.87	8.67	31.0%	74.39%
Science Content	15	6.47	13.53	7.06	32.3%	67.7%
All	46	6.33	14.52	8.19	31.6%	72.6%

Table 4. Middle school camp results for correct content answers on pre and post tests.

Domain	# Items	Mean Score		Change	% Correct	
		Pre	Post	Pre-Post	Pre	Post
Nanometer scale	31	11.83	16.93	5.1	51.4%	73.6%
Science Content	15	11.87	16.27	4.4	51.6%	70.7%
All	46	11.85	16.74	4.89	51.5%	72.8%

Table 4. High school camp results for correct content answers on pre and post tests.

As can be seen from these results there is significant gains across all three domains – nanoscale concepts, science content, and all questions combined. Learning outcomes are particularly strong for the middle school group, an important group to reach as this is often where students loose interest in STEM topics. These results clearly confirm the initial results of the learning gains seen in the 2009 camps (Table 3). We interpret this to indicate that summer camps in NSE can enhance student knowledge of nanoscale science but also science content. We conclude that offering a nanotechnology focused camp with strong science content can increase student knowledge and interest in STEM – the desired outcome of the Georgia Tech model.

Model II –

The NNIN site at the University of California Santa Barbara (UCSB) offers a different model for nanotechnology camps for secondary school students. The site has provided approximately 30 two-day nanofabrication camps – also called "Chip Camps" during which participants are introduced to nanoscale science and engineering, fabricate a micro-resistor (found in all electronics), learn laboratory protocols and safety procedures, and design and test an experiment in USCB's cleanroom facility. Participants are recruited from area high schools and in particular from underrepresented groups. Several UCSB area schools have high proportions of Hispanic students.

"The whole experience was great. I enjoyed it and found it helpful talking one-on-one after doing the whole project. I felt I understood it more when I was going over it. Using the equipment was a great experience for me. I've never used anything like it. Thank you for this. I've learned so much from it all." UCSB camp participant

The USCB camp's focus/goal differs from the Georgia Tech model in that it has been implemented to show students that science and engineering is something they are capable of doing and that they can consider STEM for future education and career choices. This purpose differs from the Georgia Tech camp which seeks to have the students gain content knowledge as well as develop an interest in STEM and NSE.

"I learned so many new things in this program. I honestly had no clue how chips were made, but because of this program that changed, I feel very educated about the process of making chips now. Also, I feel that I've learned a lot about lab protocol. I had a great time! Thank you! It was really a food experience and helped me thing about pursuing a career in science!" UCSB camp participant

The chip camp focuses on processes of using light and chemicals to create devices in a cleanroom environment. Students are guided through the process with many questions regarding what would occur if steps were altered and then these alterations are tested. The fabrication procedures are reinforced outside the cleanroom by using LEGO® models to recall the steps and processes used as well as the purpose of each of these steps. Table 5. lists the topics and activities for a typical two day chip camp.

Time	Topic
Day 1	
8:30	Introduction to nanotechnology Size and scale activity
9:00	Cleanroom - Photolithography
11:00	Cleanroom – Metal Deposition
12:00	Lunch break
1:00	Cleanroom – complete wafer
3:00	Reinforcement activity – Modeling Nanofabrication Processes
Day 2	
8:30	Nanoproducts Activity
10:00	Experiment: Changing Parameters
12:00	Lunch
1:00	Experiment: Changing Parameters
3:30	Wrap up

Table 5. Sample agenda for UCSB Chip Camp

As noted above, the UCSB camp was not designed to enhance STEM content knowledge but rather increase student interest in STEM education and careers. Figure 2 clearly indicates that the participants enjoy the hands-on nature of the program with nanoscale science not being a major component of this interest. This confirms our belief that NSE can be used as a tool to excite interest and learning in STEM. NSE in these camps is not the primary focus of interest but the science underscoring the STEM concepts and interest. A small portion of the participants liked the ability to design their own experiment which they could also test in the laboratory. The results are consistent with NNIN's belief that nanoscale science and engineering topics can be the underpinning to excite students with regards to STEM.

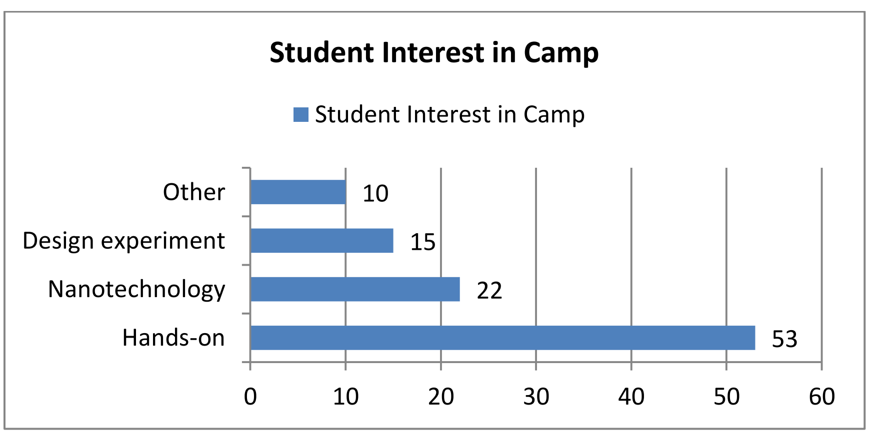


Figure 2. Survey responses regarding components of Chip Camp.

Figure 3 examines the impact the camp had on the participants' future career choices in STEM related fields. The results indicate that the camp succeeded in influencing possible education and career choices with only a small percentage of participants indicating that the camp had not affected future choices. Importantly, when examining responses from only the Hispanic students, there is a strong positive impact on STEM careers. The UCSB camp leader speaks fluent Spanish so ESOL participants were easily included in the activities perhaps influencing their comfort level with the camp and thus interest in STEM.

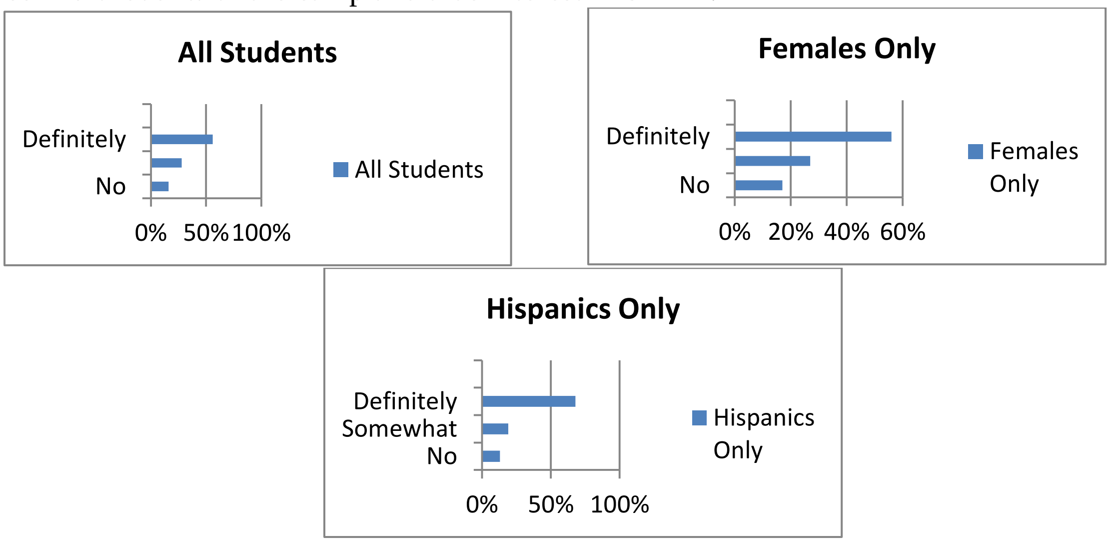


Figure 3. Response to the question: "Has the Nano-Camp affected your career choice towards a STEM-related field?"

UCSB has recently begun collecting information on where former camp participants have gone following graduation from high school. These data are from one school that has participated annually in the chip camp and are provided by the teacher so are anecdotal and not quantitative results. However, until a more rigorous analysis is implemented by conducting a follow-up study of participants, these results provide us with some insight into student education paths. Of these six students, five are Hispanic.

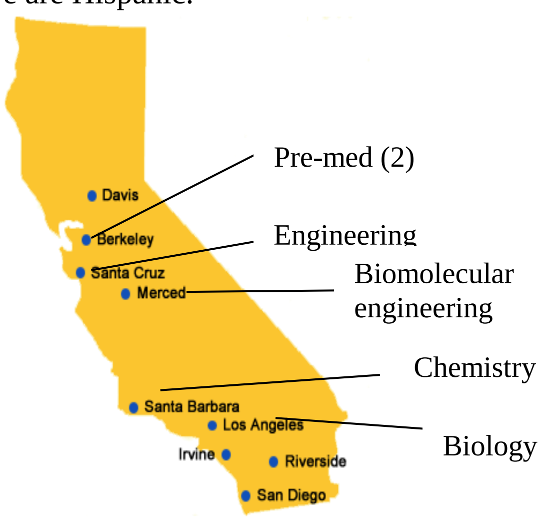


Figure 4. Universities and majors of camp participants.

We also have other anecdotal evidence from this same teacher regarding attitudinal changes in the participants. This school has the following demographics: 85% Hispanic; 8% White, non-Hispanic; 4% Asian; 1% Black; 2% Multiple/Other; and 20% English Learners. He has noted the following outcomes with his students:

- Enthusiasm in science class increased post camp
- Participants applied themselves in science class
- Grades moved from C to B+ in science
    - Other classes also reported improved learning
- ESOL students gained confidence in learning and class participation
- ESOL students set goals to become scientists and engineers

While not conclusive results, these teacher observations indicate improved learning skills particularly for underrepresented minority students. It is because of this observed impact that the teacher continues participation in the camp with his students.

Summary

This paper presents two approaches to providing nanoscale science and engineering to secondary science students in informal settings. Summer camps offer an opportunity to bring new and exciting science topics to students and allow them to explore STEM topics without the constraints common to the classroom. The results for the Georgia Tech camp clearly demonstrate that camps can enhance student content knowledge. The UCSB camps have been successful in encouraging secondary students to consider STEM careers and have been very successful in doing this with Hispanic students. It will be important to follow-up with the UCSB participants to determine if the interest in STEM education pathways was maintained well after participation in the camp. We conclude that science-based camps offer the opportunity to excite students not only about nanoscale science and engineering but also STEM.

References Cited

[1] National Academies of Science Engineering and Medicine, *Rising Above the Gathering Storm*, National Academy Press, Washington, DC, 2007.

[2] "The Nation's Report Card: Science 2009", National Center for Education Statistics, Washington, DC, 2010.

[3] Institute for Education Sciences, "NAEP Mathematics 2011 State Snapshot Reports", National Center for Education Statistics, Washington, DC, 2011.

[4] Fleishman, H.L., P.J. Hopstock, M.P. Pelczar, and B.E. Shelley, "Highlights from PISA 2009", National Center for Education Statistics, Washington, DC, 2010.

[5] Carnevale, A.P., N. Smith, and J. Strohl, "Help Wanted: Projections of Jobs and Education Requirements through 2018," Georgetown University Center on Education and the Workforce, Washington, DC, 2010.

[6] Roco, M. "Converging Science and Technology at the Nanoscale: Opportunities for Education and Training", Nature Biotechnology, Vol. 21, No.10, pp. 1-3, 2003.

[7] Roco, M. "The Long View of Nanotechnology Development", *Nanotechnology Research Directions for Societal Needs in 2020*, M.C. Roco, C.A. Mirkin, and M.C. Hersam (eds), Springer, New York, Chap. 1, pp. 1-28.

[8] Committee to Assess the Capacity of the U.S. Engineering Research Enterprise, *Engineering Research and America's Future: Meeting the Challenges of a Global Economy*, 2005, National Academy of Engineering, pp 50.

[9] National Research Council. *Engineering Research and America's Future: Meeting the Challenges of a Global Economy*. The National Academies Press, Washington, DC, 2005.

[10] Principles Committee, Innovate America: *Thriving in a World of Challenge and Change*, Council on Competitiveness, Washington, DC, 2004.

[11] Falk, J.H. and L.D. Dierking, *Lessons without Limits: How free-shoice learningis transforming education*. AltaMira Press, Walnut Creek, CA, 2002.

[12] Bell,P., B. Lewenstein, A. W. Shouse, and M. A. Feder, *Editors*, *Learning Science in Informal Environments: People, Places, and Pursuits*, National Research Council, Washington, DC, 2009.

[13] Clark, R., A. Harris, and W. Allen, After School Youth Programs: How they affect youth's educational progress and overall development. Report for the W.K. Kellogg Foundation, Battle Creek, MI, 2001.

[14] Miller, B., Critical Hours: Afterschool programs and educational success, Report for Nellie Mae Education, Quincy, MA, 2003.

[15] Noam, C., Editor, Afterschool worlds: Creating a new social space for development and learning, Jossey Bass, San Francisco, CA, 2004

[16] National Research Council. *Surrounded by Science: Learning Science in Informal Environments*. Washington, DC: The National Academies Press, 2010.

[17] Quigley, C., Khemmawadee, P., and Akerson, V.L., If we teach them, they can learn: Young students views of nature of science aspects to early elementary students during informal science education program, Journal of Science Education, v. 21 No.7 pp. 887-907, 2010.

[18] Rivera Maulucci, M.S. and Brotman, J.S., Teaching Science in the City: Exploring linkages between teacher learning and student learning across formal and informal contexts. The New Educator, v. 6 pp. 196-211, 2010.

[19] Holmes, J.A., Informal learning: student achievement and motivation in science through museum-based learning. Learning Environments Research. V. 14 no. 3 pp 263-277, 2011.

[20] Fenichel, M. and Schweingruber, *Surrounded by Science*, National Academy Press, Washington, DC, 240p., 2010. Outside the Classroom: Special Report on Informal Science Education. Accessed at http://www.edweek.org/ew/collections/sciencereport-2011/index.html.

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