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Recommended Citation

Adamchuk, Viacheslav I.; Nugent, Gwen; Barker, Bradley S.; and Grandgenett, Neal, "The Use of Robotics, GPS and GIS Technologies to Encourage STEM-Oriented Learning in Youth" (2009). *Teacher Education Faculty Proceedings & Presentations*. 12.
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The Use of Robotics, GPS and GIS Technologies to Encourage STEM-Oriented Learning in Youth

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Abstract

In our technology rich world, the educational areas of science, technology, engineering, and mathematics (STEM) play an increasingly essential role in developing well-prepared specialists for the 21st century workplace. Unfortunately, interest in these areas has been declining for a few decades. Various innovative educational initiatives in formal and informal learning environments have been undertaken nationally to attempt to encourage STEM-oriented learning. Funded by the National Science Foundation, the particular program described in this paper focuses on middle school youth in non-formal learning environments. The program integrates educational robotics, Global Positioning System (GPS) and geographic information system (GIS) technologies to provide educational experiences through summer camps, 4-H clubs and afterschool programs. The project's impact was assessed in terms of: a) youth learning of computer programming, mathematics, geospatial concepts, and engineering/robotics concepts and b) youth attitudes and motivation towards STEM-related disciplines. An increase in robotics/GPS/GIS learning questionnaire scores and a stronger self-efficacy in relevant STEM areas have been found through a set of project-related assessment instruments.

Introduction

The national economy of the United States is highly dependent on advanced technology. Unfortunately, maintaining this technological infrastructure and U.S. competitiveness hinges upon dramatic improvements to K-12 mathematics and science education. The abysmal state of science, technology, engineering, and mathematics (STEM) education in the U.S. is most overtly evidenced when standardized test scores of American students are compared to those of their international peers: by age 15, U.S. students perform relatively poor in mathematics and drop below the global average in science literacy¹. A more recent report by Education Week² confirmed that such trends are continuing, with U.S. students scoring in about the middle of international mathematics and science comparisons, enhancing calls for new approaches to STEM instruction.

One promising approach to increasing STEM attitudes, knowledge, skills and workforce capacity is the use of robotics and geospatial technologies as an instructional platform. Through hands-on experimentation, such technologies help youth transform abstract mathematics and science concepts into concrete real-world applications. Recent improvements in cost and complexity make it possible for even relatively young children to engage in hands-on experimentation with robots, Global Positioning System (GPS) receivers and geographic information system (GIS) software.

Robots have the potential to change and enhance the learning process in education³. It is most remarkable that computer-based technologies can be used as “mindtools” which involve students in using modern technologies to solve problems⁴. Traditional education practices typically utilize a relatively direct form of instruction whereby students learn from the “technology” (e.g. drill and practice exercises), while in contrast, when using “mindtools” such as robotics, students learn with the “technology”.

When considering spatial technologies like GPS and GIS, similar to robotics, there is a growing potential for educational application. GPS/GIS have become important tools in precision agriculture and natural resources management, which are relevant to youth in rural communities, often suffering directly from poor performance in STEM areas. Thus, GIS maps allow users to visualize geographic data to aid agriculture-related decision-making processes. Data used in the GIS maps can also be obtained using small handheld GPS receivers, which are easy to use even at a middle school age. Combined, the GPS and GIS technologies provide a powerful set of tools to analyze and interpret spatial information, and represent a useful context for applied learning.

The long-term goal of the program described in this paper is to improve STEM learning outcomes and attitudes of 11-15 years old youth. Using robotics and GPS/GIS concepts, the program seeks to: 1) promote youths’ interest in STEM fields, 2) introduce basic technology skills, 3) foster problem solving and inquiry skills, and 4) encourage teamwork.

Program Overview

Funded by National Science Foundation (NSF, Washington, DC) in 2006, the “Robotics and GPS/GIS in 4-H: Workforce Skills for the 21st Century” project developed and implemented a two-year non-formal education program. Targeted at 4-H clubs and afterschool programs for youth of 11-15 years old, the curriculum includes a total of 240 contact hours, including two 40-hour summer camps and 80 hours of program participation during school year. Many curriculum activities have been published by the project and can be found at <http://4hset.unl.edu>.

In Year 1 youth are introduced to the basic of robotics, learn to understand and manipulate digital geographic maps and gain experience with GPS-based navigation and data collection. Year 2 is dedicated to various indoor and outdoor activities integrating the technologies and exploring their potential in the world of agriculture and natural resource management. Each activity consists of an introductory large group activity, prescribed exercise and an additional optional challenge.

The LEGO Mindstorms NXT kit (LEGO Systems, Inc., Enfield, Connecticut) has been selected as the main robotics platform. The unit has three output and four input ports. Our activities use the output ports to operate electrical motors (two for maneuvering and one for a mechanical manipulator), and the input ports are used to equip the robot with sound, ultrasonic distance, light reflectance and mechanical switch sensors. LEGO Mindstorms NXT software is used to program the robots and to upload the code via either USB or Bluetooth communication.

Garmin eTrex Legend and Rino 110 (Garmin International, Inc., Olathe, Kansas) GPS receivers have been used to log waypoints and path tracks as well as for navigation. GoogleEarth (Google, Inc., Mountain View, California) software has been used to introduce youth to the world of

digital geographic data. ArcGIS (ESRI, Redlands, California) software has helped further develop digital mapping perception and provide freedom to customize geographic data (Figure 1a). Using the DNRGarmin module (Department of Natural Resources, St. Paul, Minnesota) allowed data interface between GPS receivers and GIS software.



Figure 1. Summer camp activities: a) digital map development and b) robot navigation.

The only direct integration of robotics technology with GPS/GIS during Year 1 is a robot tracking activity, where an i-Blue747 GPS Logger (Transystem, Inc., Hsinchu, Taiwan) has been used to record geographic positions of the robot. To implement robot navigation capability (Year 2 curriculum), several stand-alone applications have been developed using LabVIEW (National Instruments Corp., Austin, Texas). Our software allows simultaneous wireless communication between a laptop computer and both the LEGO Mindstorms NXT and i-Blue747 GPS Logger so that robot motion is adjusted automatically based upon its relative position to a targeted georeferenced marker (Figure 1b). The relatively short range of Bluetooth communication (~10 m) and low GPS positioning accuracy (~2 m) have been the main limitations. However, discovering and quantifying these limitations have become a focal point of robot navigation activities.

A recently funded scale-up project has been initiated to add new partners and to broaden the scope of the education program. The use of an educational cyberinfrastructure and a train-the-trainer model to administer the curriculum are inherent challenges when expanding program participation nationally, but the project is indeed steadily growing in scale. In addition, a robotics platform (CEENBot) developed at the Peter Kiewit Institute (PKI, University of Nebraska-Lincoln, Omaha, Nebraska) has been considered as an alternative to the LEGO robotic kit. CEENBot will be capable to operate in a non-smooth surface environment with an integrated GPS receiver.

Learning Impact Research

Various instruments have been investigated to document participant learning impact during summer camps, afterschool club gatherings and other relevant activities such as short-term interventions, virtual competitions, etc. For example, in the summer of 2008 six camps were held

throughout Nebraska. A total of 147 youth (112 males and 35 females) participated. The overall mean age for the camps was 12.28 years with a median age of 12.00 years (Table 1).

Table 1. Summer 2008 Camp Participants

Camp site	Total	Male	Female	Mean age	Minority	Overnight
Omaha North	18	9	9	11.39	100%	No
Omaha South	16	9	7	11.12	56%	No
Lincoln	67	55	12	12.52	12%	Yes
Ord	10	9	1	12.40	0 %	No
Chadron	16	13	3	12.69	0%	Yes
Grand Island	20	17	3	12.80	5%	No

To measure STEM learning, a 37-item, paper-and-pencil, multiple-choice assessment, covering a variety of topics including computer programming, mathematics, geospatial concepts and engineering/robotics was developed. The overall Cronbach's alpha reliability coefficient of 0.80 was reported for this instrument. The STEM concept test was administered on the first day of the camp prior to the start of program activities. The same concept test was also administered in the morning of the last day of camp as a posttest. Administration of the pretest-posttest assessment was conducted in the same manner for each camp.

Overall there was a significant increase from the pretest ($M = 15.63$, $SD = 4.52$) to the posttest scores ($M = 20.12$, $SD = 5.60$, $t(136) = -13.71$), $p < .001$) for the combined groups. These results suggest that the 4-H robotics and the geospatial summer camp program is a promising approach for supporting STEM-related learning. Each location except for Omaha North had a significant mean increase ($p < .001$) from pre to posttest (Table 2).

Table 2. Content Questionnaire Paired Samples Test

Camp site	Mean score		Paired difference				
	Pre	Post	Mean	SD	t	df	p-value
Omaha North	10.80	10.53	.267	3.22	.32	14	.753
Omaha South	11.58	15.50	-3.92	3.55	-3.82	11	.003
Lincoln	16.87	20.87	-4.00	3.01	-10.90	66	.001
Ord	17.60	23.80	-6.20	4.21	-4.66	9	.001
Chadron	16.53	23.20	-6.67	2.90	-8.93	14	.001
Grand Island	15.89	23.78	-7.89	3.18	-10.53	17	.001

To capture changes in attitudes of the 4-H Robotics and GPS/GIS program participants, an assessment instrument was developed with eight scales: science, mathematics, robotics, and GPS/GIS task values; robotics and GPS/GIS self-efficacy; problem approach strategies and teamwork. In keeping with the goals of the project, and based on the literature on motivation, the project team chose to focus on two basic constructs: (1) *motivation*, as represented by a) the perceived value of mathematics and science, GPS/GIS technologies and robotics and b) student's self-efficacy in robotics and GPS/GIS, as well as (2) *learning strategies*, as represented by teamwork and problem solving. Our self-efficacy scales (robotics and GPS/GIS) focused on youths' self-appraisal of their confidence in performing certain robotics and GPS/GIS tasks, such as "I am certain that I can build a LEGO robot by following design instructions." By focusing on

performance tasks, these scales complemented the project multiple-choice content test, which assessed general comprehension and knowledge. The instrument also focused on two additional learning strategy constructs that were directly related to the project goals: problem solving and teamwork. The problem solving scale measured the degree to which students use specific problem solving approaches to successfully accomplish robotics tasks. Informal observations of the students had shown that they used a variety of problem-solving approaches - including trial and error as well as, less frequently, pre-planning and problem analysis.

Similar to the learning instrument, participants scored significantly higher on the posttest ($M=155.91$, $SD = 20.20$) than on the pretest ($M=147.52$, $SD = 22.03$, $t(133) = -5.09$, $p < .001$) indicating the 4-H robotics and GPS/GIS summer camps have a positive short-term effect on attitudes towards STEM topics. While most sites had pre-post increases in attitudinal means, the t-results were not as significant as those from the content test (Table 3).

Table 3. Attitudinal Paired Samples Test

Camp site	Mean score		Paired difference				
	Pre	Post	Mean	SD	t	Df	p-value
Omaha North	152.93	152.87	.067	22.72	.011	14	.991
Omaha South	148.09	153.45	-5.36	9.39	-1.89	10	.088
Lincoln	149.39	156.13	-6.75	14.95	-3.69	66	.001
Ord	148.11	161.67	-13.56	26.81	-1.52	8	.168
Chadron	138.13	151.06	-12.94	22.98	-2.25	15	.040
Grand Island	143.31	161.13	-17.81	23.89	-2.98	15	.009

Supplemental impact measurement instruments are now under development to assess long-term program impacts, including youth career selection. Experimental designs involving the use of control groups are also been employed to provide more definitive conclusions regarding intervention impacts and effectiveness.

Summary

Improving STEM education is a national challenge, and the Robotics and GPS/GIS in 4-H: Workforce Skills for the 21st Century project has been initiated to help meet that challenge and to provide a non-formal education experience for 11-15 year old youth to encourage their consideration of STEM areas for their future academic and post-graduate careers. Use of robotics, GPS, and GIS technologies under the theme of precision agriculture and natural resource management appears to appeal to many groups of youth when participating in summer camps, 4-H clubs, and afterschool programs. Positive short-term learning and attitudinal impacts have been documented using several assessment instruments. A national scale-up project is in progress with wider scope and demographics of participants involved.

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