AC 2008-2029: ENGAGING MIDDLE SCHOOL STUDENTS IN ENGINEERING: THE ROBOTICS SYSTEM DESIGN CAMP - NATURE AS INSPIRATION

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Engaging Middle School Students in Engineering: The Robotics System Design Camp – Nature as Inspiration

Abstract

We report on the development and implementation of a summer robotics camp for middle school students in this paper. Robotics is a widely used and popular activity for engaging students in the engineering design process. One of our primary goals, however, was to offer an enhancement of the typical robotics experience in order to recruit a diverse set of applicants: an experience grounded in systems engineering paradigms in a format that would appeal to an audience interested in more than robot assembly and programming. Thus, the Robotics System Design Camp: Nature as Inspiration was created. We used the analogy of natural systems (e.g., foraging ants and swarming bees) for search and discovery as a base upon which systems engineering solutions, chiefly shortest path algorithms, could be developed and applied through robotics. The appeal of this approach for middle school students is evaluated through a mixed methods approach. Results indicate that, in spite of efforts to create hands-on activities through which campers could experience the solution of shortest path problems in the context of natural systems, campers preferred the robotics activities, indicating a need to adjust the systems engineering components to be more appealing to this age group. The narratives and appended materials give interested readers sufficient information to design and implement similar outreach programs.

Introduction

Placing institutional values of professional and community service in action, the Department of Systems and Information Engineering at the University of Virginia (SIE) developed and implemented the Robotics Systems Design Camp: Nature as Inspiration in 2007 as a means to engage in outreach to the crucial-to-interest-in-engineering demographic of middle school students. We report on the development and performance of the camp in this paper with the goal of providing sufficient information and motivation for others to follow, since it will indeed "take a (professional and institutional) village" to combat the well-known shortfall expected in the science, technology, engineering, and mathematics (STEM) professions as the two trends of baby-boomers retiring and fewer students engaging in STEM studies collide.

The camp leadership committee determined that, to be successful, the following goals needed to be met in designing the camp: 1) to develop approaches to relate systems engineering to middle school students, and 2) to focus on hands-on activities for the campers. To that end, the leadership committee focused on the following questions:

- What impact could the camp have on middle school students' knowledge and attitudes towards engineering?
- What characteristics of hands-on activities are most exciting to middle school students?

The resulting camp design uses the theme of using natural systems as inspiration for technological systems, an idea connected to research areas of several faculty working on "swarming" algorithms for robots. This connection to faculty research in our department was effective in engaging several faculty as instructors and mentors for the camp; similarly, the connection helped in recruiting graduate and undergraduate students and a middle school teacher participating in a departmental Research Experience for Teachers (RET) as counselors. In terms of creating content that was targeted at middle school students, the camp included focused times for learning about building, and programming Lego Mindstorm robots and several activities focused on core systems engineering concepts applicable to swarming robots such as shortest path problems and searching a two-dimensional space for targets.

The report begins with a discussion of camp development events, covering the composition of the leadership team, the establishment of camp goals and objectives, and a description of planning activities. A development timeline identifying the time and order in which these activities took place follows. The camp schedule (syllabus) and accompanying narrative provide a robust description of events and activities. A sketch of camper demographics provides perspective for the discussion of the results of camp assessment activities. We end with student reflections, sharing the campers' enthusiasm and learning.

Camp Development

The initial steps taken in developing the camp were to assemble a leadership team and to establish goals and objectives for the camp. The camp leadership team was composed of faculty, staff and graduate students from the Department and a postdoctoral engineering education researcher. Among the faculty involved were two faculty heavily involved in technical research related to the mathematical concepts upon which camp activities are based, and one involved in engineering education research, teaching, and departmental administration; this latter faculty member served as the Camp Director.

The primary goal in offering this camp is to **motivate middle school students to consider studies in science, technology, engineering, and mathematics (STEM) fields through activities anchored in systems engineering**.

Secondary goals are to:

- Help students see how systems engineers apply math and science concepts to solve real world problems
- Explore connections between systems engineering and other "systems" fields: for 2007, connections with ecology were the focus
- Assist students in developing skills necessary to tackle open-ended, real world problems such as creative thinking, problem definition, and decision-making
- Help students develop teamwork and communication skills which are applicable to engineering, other professions, and everyday activities

With these goals, the primary challenge faced by the camp leadership team was to offer an engaging camp for middle school students built on complex concepts from systems engineering.

Finding an approach to address this challenge was a multi-step process. As shown in Figure 1, this process started by examining systems engineering as a whole for areas that were the most promising candidates for engaging middle school students.

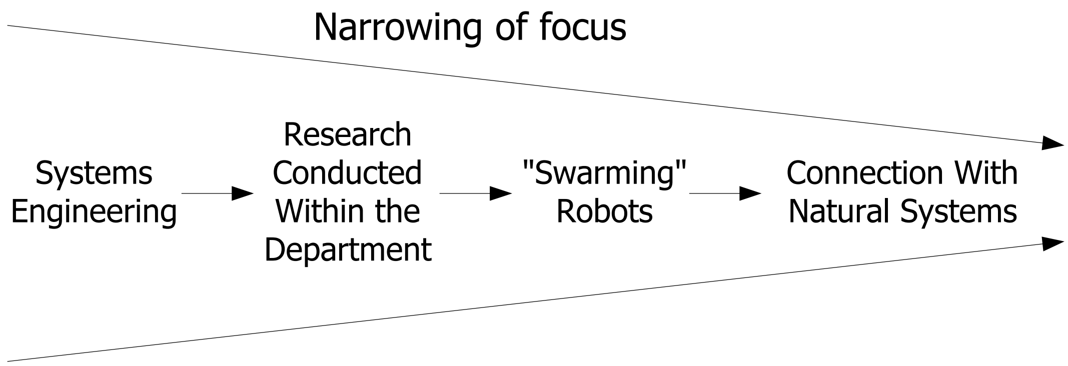

Figure 1. Development of Camp Theme

A critical early decision was to focus camp activities in areas linked to research conducted by Department faculty. This decision increased the buy-in from faculty, engaged more faculty and graduate students in camp development, and distinguished our camp from other camps.

The specific systems engineering area around which we developed the camp was "swarming" robotics. The underlying idea behind swarming robots is that several relatively "dumb" robots can be programmed to work together to perform complex tasks without a central computer coordinating their actions. LEGO Mindstorm robots were selected for use in the camp due to faculty members' use of LEGO robotics in their research and the known popularity of LEGO robotics with K-12 populations. Within the area of swarming robotics, the leadership team decided to focus the camp on the analogies from nature such as ants, bees, and fish – all of which exhibit complex, coordinated system behavior without centralized control. One reason for focusing on using "nature as inspiration" as a theme for the camp was the concern that a pure "robotics" camp would likely attract significantly more applications from white males than females and males from underrepresented populations in STEM. We hoped to attract a more diverse set of applicants with a camp agenda that paired a strong focus on natural systems with robotics.

Early in the development of the camp, the leadership team decided that we would offer scholarships so that cost would not be a factor in preventing anyone from attending. We wanted to foster economic diversity among the camper population in addition to gender and ethnicity. Two corporate sponsors, with whom the Department has a long and mutually beneficial relationship, contributed scholarship funds. The cost for attending the camp for students on scholarship was $25; otherwise, it was $225. This figure was based on costs for similar camps in our geographic area.

The leadership team also addressed camp logistics. Primary decisions made included food service (students brought their lunch and we provided an afternoon snack), consent documentation (we adapted validated forms from a team member's day care center), disciplinary policies, graduation requirements, and venues (ultimately, three adjacent computer-equipped classrooms which could be secured and a courtyard for outside activities).

Camp Development Timeline

The following is an outline of key activities and milestones in developing the camp.

Fall 2006:	Leadership team formed
December 2006:	Major camp theme and structure defined
Jan.-Feb. 2007:	Marketing plan developed, connections with local schools formed, administrative (i.e., Dean's office) support established, cost for attending camp established, external funding gained for scholarships, NSF Research Experience for Teachers (RET) proposal developed
March 2007:	Daily goals for camp defined, detailed development work split among leadership team, camp marketing materials distributed
April 2007:	Camper applications received, camp counselors recruited from SIE undergraduate and graduate students (five total applied, all hired – all males; two graduate students and three undergraduates; one Latino [Colombia native], one Asian-American, and three White American)
May 2007:	Decision to add "pilot" session of camp instead of down-select from applicant pool, purchasing of key materials (LEGO Mindstorm kits)
June 2007:	Final detailed development of camp activities, camp logistics and policies/forms developed and sent to campers, evaluation plan finalized, RET participant joins camp staff
July 2007:	Finalized guest speakers, prepared student workbooks
July 13, 2007:	Two-hour final review of materials with camp counselors
July 16-20, 2007:	First camp session ("pilot" session)
July 23-27, 2007:	Second camp session
August 2007:	Post-camp analysis, reporting, and feedback

A particularly important decision occurred in May, when we had received nearly forty applicants for a camp designed for only twenty. While we considered accepting only twenty students, we struggled with identifying the appropriate criteria to use in that process. Rejecting roughly half of the applicants did not align with our goal of motivating students to consider study of STEM fields. Further, we felt that taking the first twenty applicants would unfairly disadvantage students on an irrelevant criterion: timeliness. Therefore, we decided to add an additional session of the camp, a "pilot" week, and accepted all of the applicants. The original plan had been to work with the counselors for one training week (without any campers) during the week prior to the camp. By adding a second session of the camp, this training week was replaced with a "pilot" camp with twenty campers. This decision proved to be very felicitous: the "pilot" revealed several activities and events which required "tweaking" to various degrees. The experiences of the first session contributed, in no small measure, to the success of the second. For example, the Introduction and Communication (Lego Block) exercises on Monday were changed based on the results of Week 1 and the RET staffer's suggestions. The Week 2 versions scored higher on assessments than the Week 1 versions, so we feel comfortable concluding that the changes were successfully implemented.

Camp Structure

The camp was a week-long day-camp, running from 9:00 AM to 4:00 PM each day. The primary morning activities focused on hands-on systems engineering activities while the primary afternoon activities focused on LEGO Mindstorm robotics. A final challenge which required both systems engineering and robotics knowledge was introduced on Monday and served as a motivating force to integrate the systems engineering and robotics "halves" of the camp.

A day-by-day schedule is provided in Figure 2.

Monday morning activities focused on getting the campers comfortable with each other and the counselors, creating teams of students, introducing the teams to the final challenge, gathering pre-camp evaluation data, and taking a group photo for the attendance certificate. The team population method was strongly grounded in STEM education research.[1-4] Our primary goal was to avoid isolation of students from underrepresented populations in STEM; secondary goals were to group campers by experience and then age, with the objective of maintaining diversity on teams by not placing family members or students from the same school on the same team. Monday afternoon was the first exposure campers had to the LEGO Mindstorm kits in the camp; familiarity was gained through a series of exploratory exercises.

Tuesday through Thursday mornings were the times for the primary "hands-on systems engineering" experiences. The format for each of these mornings was similar: establish terminology, directly experience a problem to realize why solving it is difficult, learn how to solve the problem, and apply knowledge of how to solve the problem to a more challenging scenario. For example, on Tuesday, campers learned relevant terms for shortest path problems (e.g., node, arc) with a simple problem. Next, campers were challenged to find the shortest path through a network of cones laid out in a large field. Following this activity, campers worked in pairs to complete a worksheet[5] which guided them through the steps of Djikstra's algorithm, a procedure for solving shortest path problems. The worksheet used the same network as the campers had just encountered outside in the field. Finally, they returned outside to try to solve a more challenging shortest-path problem that was marked out by cones.

	Monday	Tuesday	Wednesday	Thursday	Friday
	drop off	drop off	drop off	drop off	drop off
9:00	Welcome	Shortest Path Activity	Ant Shortest Path Activity	Search & Discover	Robotics: Final testing and presentation preparation
	Orientation Activity				
	Survey				
10:00	WiCAT Demo + Final Challenge Intro				
11:00	Team Building Activity		Ant Speaker		
11:30					Survey
					Lunch / DARPA Challenge Car
12:00	Lunch / Video	Lunch / Video	Lunch / Video	Lunch / Video	
	Robotics Day 1 - Explore	Beekeepers	Robotics Day 3	Robotics Day 4	
1:00					Final Prep and Parents' Info
		Robotics Day 2 - Line Following			
2:00					Final Presos and Demos
3:30	Reflection	Reflection	Reflection	Reflection	Recognition
	Pick-up	Pick-up	Pick-up	Pick-up	Pick-up
4:00					

Figure 2. Day-by-Day Schedule

Additional background and information on natural systems were provided by two guest speakers, one on ant behavior and one on bee behavior, and by a video on robotics inspired by natural systems, which was shown during lunch. The “natural systems” focus also influenced the design of the Final Challenge, in which a human-in-the-loop version of swarming behavior was incorporated.

The Tuesday – Thursday afternoon robotics curriculum included developing (design, assembly, programming, and testing) line following/sensing robots, learning how to use a Wii controller to “drive” the robots, and preparing for the Final Challenge.

Friday was the day for the teams to demonstrate the knowledge they gained throughout the week through competition in the Final Challenge. The task confronting the teams was to use swarming behaviors to find the shortest path between a “Rescue Operation Center” and a major city directly hit by a hurricane. Refer to Appendix A for a detailed description of the Challenge. Additional preparations for the Challenge occurred in the morning. Family members were asked to join us beginning at 11:30 am. The campers and their families were then given an introduction to Tommy II, our institution’s entry in the DARPA Urban Challenge for autonomous vehicles and a “grown-up” version of the campers’ robots, while camp staff set up for lunch. After lunch and a Q/A session with camp staff and Department faculty, parents met with counselors from Admission and a local high school. The meeting’s objective was to introduce the parents to the plan(s) of study that would best prepare their child for successful studies in the STEM disciplines at a major research university. The Associate Dean for Undergraduate Studies was also available for questions and comments. The campers made their final preparations for the Challenge while their parents attended this meeting. Reunited in the largest of the classrooms for the Challenge, families cheered on their campers as the teams competed. Media coverage, both print[6] and TV[7], of Challenge activities in the second session added to the excitement. An awards and graduation ceremony closed the camp session.

Demographics of Camp Participants

<u>Session 1</u>

Gender/Ethnicity: 18 males (3 Asian American and 3 Hispanic American) and 2 females
Grades (as of Fall, 2007): 6 sixth, 5 seventh, and 8 eighth graders (2 not reporting)
Schools Represented: 12

<u>Session 2</u>

Gender/Ethnicity: 18 males (2 African American) and 3 females (1 African American)
Grades (as of Fall, 2007): 1 fifth, 12 sixth, 4 seventh, 1 eighth, and 1 ninth graders (2 not reporting)
Schools Represented: 11

Assessment

The goal of camp assessment is to provide data for the investigation of the following research questions (RQ):

RQ1. Are there differences in campers’ knowledge about what engineers do before and after the Robotics Systems Design Camp?
RQ2. Are there differences in campers’ attitudes about engineering, math, and science before and after the Robotics Systems Design Camp?
RQ3. What characteristics of hands-on activities are most exciting to campers?

We developed two sets of instruments to answer these questions: a pre- and post-camp assessment of attitudes towards engineering in general and systems engineering specifically, and of baseline / end of camp knowledge, skills, and abilities (KSAs); and a daily assessment (entitled "Daily Reflections") of attitudes towards that day's camp activities and engineering concepts. The former instruments were used to conduct summative assessments; the latter, formative assessments. The pre-camp assessment also gathered demographic information used in forming the work teams.

The information gathered by the pre-camp and daily assessments was also used in end-of-day debriefing and planning sessions. Diligent review of the formative assessments served their purpose: the information helped us keep the camp on track, making in-course assessments as needed. The daily "Is there anything you'd like us to know about?" question provided valuable confirmation of team / camper conflict observed by staff; with backup, we were able to proceed confidently with parental notification and, as needed, disciplinary action.

The assessment instruments used to evaluate the research questions are shown in Table 1. Again, not all of the questions on the assessment instruments support investigation of the three research questions. The answers to Questions 5 and 6 were used to form teams. Question 4 focused on whether campers' expectations for the camp were met.

Table 1. Linkage Between Assessment Instrument and Research Questions

Research Question 1 (change in knowledge about what engineers do)	**Research Question 2** (change in attitudes about engineering, math, and science)	**Research Question 3** (most exciting hands-on activities)
• Pre-Post difference on: o Q1 (what engineers do) o Q2 (what systems engineers do) o Open-ended question asking what campers think engineers do	• Pre-Post difference on: o Q3 ("I'd like to be an engineer someday") o Q7 (excited about camp/glad attended) o Q8 (interest in science) o Q9 (interest math) o Q10 (interest in engineering) • Daily open-ended question about camp activities that increased their interest in math/science	• Daily questions about specific activities

We used the results from Week 1 to reshape the assessments for Week 2. Week 2 results are reported in the following section. The Week 2 pre- and post-assessment instruments are given in Appendix C, and the Daily Reflection instruments in Appendix D.

Results

Full results from the non-open-ended question portion of the pre- and post- camp assessments for Week 2 of camp are shown in Table 2. The total number of campers was 21; the final sample size for the pre-post comparisons is 15. Two campers were not at the camp for the pre-assessment; 4 campers were not there for the post-assessment due to disciplinary issues (i.e., they were asked to leave the camp earlier in the week).

Table 2. Pre-Post Data Showing Frequency of Responses (shading: modal responses)

Question # and Question		Pre-Camp			Post-Camp		
1	In general, I know what kind of work engineers do.	**0** not at all	**6** not sure	**9** yes	**0** not at all	**4** not sure	**11** yes
2	I know what kind of work systems engineers do.	**2** not at all	**10** not sure	**3** yes	**1** not at all	**7** not sure	**7** yes
3	I'd like to be an engineer someday.	**0** not at all	**8** not sure	**7** yes	**2** not at all	**6** not sure	**7** yes
4	I know what we are going to do this week.	**1** not at all	**8** not sure	**6** yes	-	-	-
	We did just what I expected this week.	-	-	-	**0** not at all	**12** not sure	**3** yes
	I got to do the activities I wanted this week.	-	-	-	**0** not at all	**4** not sure	**11** yes
5	I am familiar with Lego Mindstorm robots.	**3** not at all	**6** somewhat	**6** very	**0** not at all	**3** somewhat	**11** very
6	My robot programming experience is:	**6** none	**7** a little	**2** a lot	**0** none	**8** a little	**7** a lot
7	I am excited about attending this camp.	**0** not at all	**5** somewhat	**10** very	-	-	-
	I am glad I attended this camp.	-	-	-	**0** not at all	**6** somewhat	**9** very
8	My interest in science is:	**0** low	**2** medium	**13** high	**0** low	**5** medium	**10** high
9	My interest in math is:	**0** low	**5** medium	**10** high	**0** low	**4** medium	**11** high
10	My interest in engineering is:	**0** low	**6** medium	**9** high	**2** low	**5** medium	**8** high

Modal analysis shows changes from pre- to post-camp on several questions (2, 3, and 5). The only statistically significant changes, determined through a Wilcoxon signed ranks test of the paired responses, were for Question 5 ($n=14$, $z=-2.310$, $p=0.021$) and Question 6 ($n=15$, $z=-2.810$, $p=0.005$). Given the high probability of Type II error with such a small sample ($n=15$), it is not surprising that additional questions were not statistically significant. As well, we would expect that camper familiarity with robots and their programming would increase after five days of experience.

Recall that the camp's primary goal is to motivate middle school students to consider studies in STEM fields through activities anchored in systems engineering. Campers are self and/or parental selected, so it is not surprising that self-assessed attitudes towards science, math, and engineering are high both pre- and post-camp (Questions 3, 8, 9, and 10). A qualitative review of pre- and post-camp responses and a quantitative assessment of ratings indicate that we did succeed in educating the campers with respect to systems engineering (Question 2), robot design (Question 5), and robot programming (Question 6).

While quantitative results regarding campers' knowledge of what engineers do showed no change (Question 1), qualitative analysis of their responses to the open-ended question "What do engineers do?" revealed growth in knowledge through the post-assessment responses. Campers had a general idea of what engineers do prior to attending camp; 14 reported some version of "build and design things" in the pre-camp assessment. Participation in camp helped a majority of campers to provide a more robust description of the engineering profession in the post-camp assessment; for example, 5 campers added some version "help people through technology" to their more descriptive "build and design" statement. Examples of pre-and post-paired responses, showing the knowledge growth, are given in Table 3.

Table 3. Examples of Increasing Robustness in Qualitative Responses to the Query "What do engineers do?" (Responses Paired and Unedited)

Pre-Camp Responses	Post-Camp Responses
Design objects or improve designs that'll help people in daily life - or in science (e.g., astronaut)	Engineers work to help people's lives become easier and to help improve technology so we can become a better world.
Build things that will hellp (sic) us now and in the future.	Build things to help people, find shortest paths, and much much more
They can design stuff and build it. They can fix things and try to make it better.	They can design and build stuff. They try to build thinggs (sic) effectively and put them in good
?	There are many types but they all work to help people
Design things.	Design and test things.

The camp counselors consistently received rave reviews in the post-camp assessment for both sessions. This result underscores the need to select counselors who will actively, intelligently, and empathetically engage with campers. Having outstanding, committed, knowledgeable counselors is a primary contributor to camp success.

The daily assessments gathered the data that campers preferred the afternoon activities (robot building – that's all many of the male campers wanted to do…) over the morning activities – especially when it was a typical July day: hazy, hot, and humid! The morning activities specifically not liked are Frisbee (break/post lunch activity), name ball (Week 1 orientation activity), and shortest path activities. The beekeepers' presentation, being more of a lecture than an interactive discussion, was less preferred than the "ant guy's" presentation. We also learned through the Week 1 daily assessments that the campers, especially the younger ones, were having difficulty linking concepts and activities. We used that information to compliment the conversational pedagogic delivery method with PowerPoint presentations listing instructional objectives and planned outcomes in Week 2, and update the Daily Reflections instrument to assess the degree to which campers were able to link concepts and activities.

Campers' preference for robotics to the shortest path activities and other "systems engineering" components is not entirely surprising, given the age group and range of interests; the assessment results indicate that the systems engineering activities are ones where improvement in engaging camper interest is certainly possible in future iterations of the camp. To that end, the camp staff and leadership team have identified the following approaches to obtain the desired improvement:

1. Construct more difficult example problems – it is not clear that the campers ever realized how hard a shortest path problem can be and why a specific approach is needed to solve it.
2. Create a series of challenges that will require the campers to utilize systems engineering knowledge more heavily when programming and operating their robots.
3. Focus on a larger variety of types of systems engineering problems – the focus on shortest path for two mornings was, perhaps, too intense for the represented age groups.

We are currently planning Summer 2008 camp sessions based, in large part, on these experiences and assessment results. Due to camper interest, we are planning separate beginner and intermediate sessions. Since the larger number of campers were rising sixth graders, we are considering having a session for only that age group. The developmental differences between rising sixth graders and rising eighth graders in Week 1 proved to be too great at times, resulting in the rising eighth graders session often mentally disengaging from camp activities.

In summary, results for RQ1 show that, while campers generally felt that they knew what engineers do before attending the camp, their knowledge of engineering work was more robust after the camp than before. A slight increase in camper's self-reported knowledge about what systems engineers do is seen through a modal analysis of the results, but this increase was not statistically significant. Results for RQ2 indicate that the campers were already highly interested in math, science, and engineering and that no significant changes in their interest occurred during the week of the camp. With respect to RQ3, the robotics activities had a clear advantage over the systems engineering activities in exciting the campers. Specific weaknesses of the systems engineering activities identified by the campers and camp staff include their lack of difficulty, the indirectness of their connectedness to the robotics challenges, and the lack of variety of systems engineering topics covered.

Campers' Reflections[6]

"I've been interested in robotics, so this camp has really been fun for me. The most fun was testing the robots for the first time, because they usually didn't work. We would all laugh and then figure out what was wrong. I'm going to take more math and science so I can learn more about it."

"I'm very interested in robots, and I like Legos, too. This camp was better than I thought it was going to be. I didn't know we were going to have a race course and be able to use Wii remotes. I learned a lot of things, like how to program a robot and what makes it go faster. I kind of think of robots as people, because you need to treat them nice, too. And you have to take good care of them. I see them as a friend."

Figure 3. Camp Scenes: Team Twitchy in the Final Challenge[6] and Introduction to Tommy II[8]

Acknowledgments

We thank our camp's corporate sponsors, Lockheed Martin and Northrop Grumman, for the financial support that made the camp a reality, especially with respect to scholarships; Department faculty, students, and staff whose dedication made the camp successful, especially Jill Bratton; outside speakers and counselors who so kindly donated their time to provide enrichment activities for both campers and their parents; the reviewers, for their comments; and last, but not least, the campers. We hope to see you all matriculate at U.Va. starting in 2012!

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Appendix A Final Challenge Details

PRESS RELEASE: TO BE RELEASED IMMEDIATELY

A hurricane has just hit the coast of a major city in the United States.

The closest major Rescue Operations Center (ROC) is going to send autonomous (unmanned, computer controlled) trucks to the devastated city, picking up supplies such as food and water from several distribution points on the way.

Unfortunately, the ROC has not been run effectively, so they don't have any information on the time it takes to navigate to the distribution points or the amount of supplies each point can provide to each vehicle.

Your job: advise the ROC how to quickly learn not only the shortest route to the devastated area, but also the route that will get the most supplies to the city… and soon!

###

A Rescue Team, Red team, has established a Station (Base II) and is conducting rescue missions in a devastated area (End). Given the limited amount of supplies available in Base II, the Red team has asked the ROC, located in Base I, to send as much supplies as possible to Base II. The headquarters sends autonomous vehicles that go by each node (e.g. manufacturer) picking up rescue kits that are to be transported to Base II. At the end of each run, each vehicle must have taken the kits obtained at each node to the final destination (Base II). A sample network for this problem is shown in Figure A1.

Each node (manufacturer) can only provide a fixed number of kits, so if a second vehicle goes through this node, the number of kits received would be the same as for the first run.

After some exploration runs, each team will be given the opportunity to go through and obtain a score based on the speed at which the kits are transported (only the time between nodes is measure), so that different strategies may arise (e.g. fastest path, path with more supplies).

At each node the team will be provided with aggregated information about previous trials (e.g. maximum and minimum times of a path). So for instance, if a robot is in Node *i*, information about the two possible paths leaving this node would serve as grades of path quality, but it depends on each team on how to use this information.

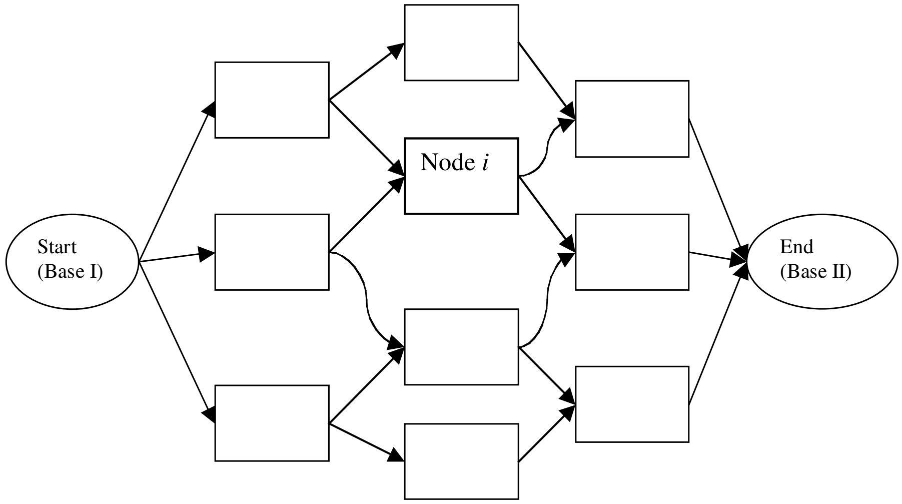

Figure A1 Sample Final Challenge Network

Appendix B Relating the Rescue Scenario to Ants Searching for Food

The challenge is meant to exemplify the concepts learned in the camp. There will be a set of nodes set up on the floor, with a distinct start and end position (See Figure A1). The robots will transverse the nodes in sequential stages meaning that there will have to be distinct choices as to what node the robot should visit next. The nodes will be connected by lines drawn on the floor as seen in Figure A1.

Conceptually, the search can be thought of as a single ant collecting food. There will be two parts to the challenge. First will be the problem of optimizing the amount of food collected in the nodes visited during a specific run. The teams will be given multiple runs over the same grid in order to gain experience and apply their knowledge of search algorithms. The second part consists in the speed in which the team completes a given run. These two components should be judged together to see which approach performs the best.

Each node represents a food source for which the ants (robots) are searching. Each will have its own unique production value and the teams will look to optimize the amount of food that the robots collect during the search. After the robot reaches a node (e.g. Node i) the amount of food will automatically be added to the team's tally for the run, and the team will be supplied with some statistics concerning the rest of the search field (e.g. upper and lower paths). This would be such things as the maximum and minimum food values for certain paths or how much food is potentially available to them with their current path options available. This information is provided so that the campers apply the concepts learnt, making use of their and others' experiences.

The second component of the challenge is the time it takes for the robots to complete the search, not accounting for decision making and maneuvering time at each node. The robots are programmed so that using the line following algorithm, developed by the campers, will be much faster than using an external control to tell the robots where to go in cases of failure.

The lines act as available paths from node to node and present a navigational challenge for the line following robot, rewarding teams with better designs. The introduction of curved paths also adds an aspect of risk to their decisions. Teams confident in their line following algorithm may choose to try more difficult but rewarding paths.

The information gathered each run by a team increases the campers' knowledge of the system, allowing them to make better decisions each time. Aggregated information, consistent of all teams' runs, would be available continually.

Appendix C Session 2 Pre- and Post-Camp Assessment Instruments

Pre-Camp Assessment

Before We Get Started…

…we'd like to ask you a few questions! Your answers will help us make camp a fun learning time for you, so we'd appreciate it if you would answer as many of the questions as possible. You have to answer the first three questions, though!

My name is: ____
I'm a (circle one) girl boy
I'll be in (circle one) 5th 6th 7th 8th grade this fall at ___________________

Please circle the answer that best describes your opinion or feeling.

1. In general, I know what kind of work engineers do.	not at all	not sure	yes
2. I know what kind of work systems engineers do.	not at all	not sure	yes
3. I'd like to be an engineer someday.	not at all	not sure	yes
4. I know what we are going to this week.	not at all	not sure	yes
5. I am familiar with Lego Mindstorm robots.	not at all	somewhat	very
6. My robot programming experience is:	none	a little	a lot
7. I am excited about attending this camp.	not at all	somewhat	very
8. My interest in science is	low	medium	high
9. My interest in math is	low	medium	high
10. My interest in engineering is	low	medium	high

Please answer the following questions. BTW, it's ok to have more than one favorite!

My favorite class in school is:
Because:

My favorite activity outside of school is:
Because:

What do you think we'll have done by Friday?
What do you think engineers do, in general?

Is there anything you'd like us to know about?

Post-Camp Assessment

Now that we're done…

…we'd like to ask you a few questions about your experiences and what you've learned this week! Your answers will help us make camp better for next year's kids, so please answer as many as possible. Thanks!

My name is: ____

Please circle the answer that best describes your opinion or feeling.

1. In general, I know what kind of work engineers do.	not at all	not sure	yes
2. I know what kind of work systems engineers do.	not at all	not sure	yes
3. I'd like to be an engineer someday.	not at all	not sure	yes
4a. We did just what I expected this week.	not at all	not sure	yes
4b. I got to do the activities I wanted this week.	not at all	not sure	yes
5. I am now familiar with Lego Mindstorm robots.	not at all	somewhat	very
6. My robot programming experience now is:	none	a little	a lot
7. I am glad I attended this camp.	not at all	somewhat	very
8. My interest in science is	low	medium	high
9. My interest in math is	low	medium	high
10. My interest in engineering is	low	medium	high
11. In general, I liked the morning activities.	not at all	somewhat	very
12. In general, I liked the afternoon activities	not at all	somewhat	very
13. I liked the camp staff.	not at all	somewhat	very
14. I liked the beekeepers.	not at all	somewhat	very
15. I liked the ant guy.	not at all	somewhat	very
16. I liked learning about college.	not at all	somewhat	very

Please answer the following questions. BTW, it's ok to have more than one favorite!

My favorite activity this week was:
Because:

My least favorite activity this week was:
Because:

Now that you've finished camp…

What do engineers do?
What else did you learn about this week?
What else would you like to tell us about camp?
Would you recommend this camp to a friend?

Appendix D Daily Reflection Instruments (Session 2, Monday - Thursday)

Monday

Please rank how you feel about… (using a 5 point Likert scale with qualitative tags, with 1 = Didn't like at all, 3 = OK, and 5 Liked a lot!)

Morning Activities
- Introduction
- WiCAT Demo
- Introduction to the Final Challenge
- Obstacle/Communication Exercise

Afternoon
- Exploring Robots

Please answer the following questions.

What did you like best about camp today?
Because:
What would you change about camp today?
Because:
What did your team do today?
How do you think engineers help people? Please give examples.
Did any activity **today** make you more interested in studying math and science?
If yes, please name the activity and give a reason why it helped increase your interest.
Is there anything you'd like us to know about?

Tuesday

Please rank how you feel about… (using the same 5 point Likert scale and qualitative tags as Monday's questions)

Morning Activities
- Shortest Path (inside)
- Shortest Path (outside)
- Do these activities help with building your robot? Yes No
- Do these activities help with programming your robot? Yes No

Afternoon Activities
- Robot Building
- Robot Line Following
- Robot Racing

Special Speaker (Qualitative tags for the second question are *not at all*, *somewhat*, and *tons!*)

Beekeepers

How helpful was this talk with respect to your bot?

Any comments on the speakers?

Please answer the following questions.

What did you like best about camp today?
Because:
What would you change about camp today?
Because:
What did your team do today?
How do you think engineers use the shortest path and line following principles? Please give examples.
Did any activity **today** make you more interested in studying math and science?
If yes, please name the activity and give a reason why it helped increase your interest.
Is there anything you'd like us to know about?

Wednesday

Please rank how you feel about… (using the same 5 point Likert scale and qualitative tags as Monday's questions)

Morning Activities

Ant Shortest Path (inside)
Ant Shortest Path (outside)

Do these activities help with building your robot?	Yes	No
Do these activities help with programming your robot?	Yes	No

Afternoon Activities

Robot Building
Robot Racing

Special Speaker (Qualitative tags for the second question are *not at all*, *somewhat*, and *tons!*)

Ant Guy

How helpful was this talk with respect to your bot?

Any comments on the speaker?

Please answer the following questions.

What did you like best about camp today?
Because:
What would you change about camp today?
Because:
What did your team do today?
What do you think would be a fun thing about being an engineer? A not so fun thing? Please give examples.
Did any activity **today** make you more interested in studying math and science?
If yes, please name the activity and give a reason why it helped increase your interest.
Is there anything you'd like us to know about?

<u>Thursday</u>

Please rank how you feel about… (using the same 5 point Likert scale and qualitative tags as Monday's questions)

Morning Activities

Search and Discover (inside)		
Search and Discover (outside)		
Do these activities help with building your robot?	Yes	No
Do these activities help with programming your robot?	Yes	No

Afternoon Activities (Qualitative tags for the last question are *not at all*, *somewhat*, and *tons!*)

Robot Line Following
Robot Wii Control
Racing
Decision Making w/ (staff)
How helpful was (staff's) info
with respect to your bot?

Please answer the following questions.

What did you like best about camp today?
Because:
What would you change about camp today?
Because:
What did your team do today?
How do you think engineers help people? Please give examples.
Did any activity **today** make you more interested in studying math and science?
If yes, please name the activity and give a reason why it helped increase your interest.
Is there anything you'd like us to know about?