Implementing iCODE (Internet Community of Design Engineers): A Collaborative Engineering and Technology Project for Middle and High School Students in Urban Settings

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ABSTRACT: Teams from UMass Lowell and Machine Science have collaborated to create an online learning system for secondary students in urban areas in Massachusetts. The Internet Community of Design Engineers (iCODE) is a first of its kind resource, incorporating step-by-step design plans for IT-intensive, computer-controlled projects, on-line tools for programming microcontrollers, resources to facilitate on-line mentoring by university students and IT professionals, forums for sharing project ideas and engaging in collaborative troubleshooting, and tools for creating web-based project portfolios. This paper describes Year 1 successes, as well as steps to enhance the learning experience for students and the teaching experience for educators during Years 2 and 3.

OVERVIEW OF THE PROGRAM
With funding from the NSF’s ESIE ITEST Program, the University of Massachusetts Lowell (UML) and Machine Science Inc. have completed the first year of a three-year curriculum development, implementation, and research project designed to support IT-intensive engineering design programs for students in grades 7 to 12. The core of the project is the development of an on-line learning system—the Internet Community of Design Engineers (iCODE)—a first of its kind resource, incorporating step-by-step design plans for IT-intensive, computer-controlled projects, on-line tools for programming microcontrollers, resources to facilitate on-line mentoring by university students and IT professionals, forums for sharing project ideas and engaging in collaborative troubleshooting, and tools for creating web-based project portfolios. This collaborative online environment is being used to structure self-directed, hands-on learning in Massachusetts schools and community centers during a three-year grant period. The overall objective of iCODE is to increase the likelihood that participating middle school and high school students will pursue IT and STEM careers, by engaging them in intensive, hands-on IT learning experiences. A secondary goal is to enable educators to learn about engineering and technology instruction by providing them with tools, training, and student mentors to support instruction in after-school design sessions. Educator feedback is seen as vital to the development and implementation of this project.

Goodman Research Group (GRG), in partnership with the iCODE team, is conducting the external formative and summative evaluation of this. GRG’s evaluation of the program involves collecting data over the three years of this project from multiple sources including youth participants, industry mentors, and key players at participating organizations. Educator feedback is being used as a form of assessment to help shape Years 2 and 3 of this project.

During 2006-2007 the iCODE system was piloted and evaluated as a Youth-Based ITEST project, serving more than 175 students in racially diverse and economically disadvantaged communities in Boston and Lowell, Massachusetts. Reflecting the diversity of these communities, the project attracted a relatively high percentage of African-American, Latina/o, and Southeast Asian students. Throughout the year students had opportunities to engage in rigorous, IT-intensive, hands-on activities, using microcontroller kits that had previously been developed and classroom-tested by UML and Machine Science. About one-third of the participants stay involved for two years, with a small group returning for all three years. Among the first cohort of educators, most had some previous experience teaching engineering and design to their students.

Together, the project partners offered a serious of age-appropriate, computer-controlled design projects, extending from middle school to high school. Students in Lowell did projects based on the Handy Cricket—a microcontroller kit that can be used for sensing, control, data collection, and automation. Programmed in Logo, the Handy Cricket provides an ideal introduction to microcontroller-based projects, suitable for students in grades 7 to 9. Boston students worked with Machine Science’s more advanced kits, which challenge students to build electronic circuits.

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from their basic components and then write microcontroller code in the C programming language. Machine Science’s kits and curriculum are intended for students from grades 9 to 12.

Microcontroller technology is an unseen but pervasive part of everyday life, integrated into virtually all automobiles, home appliances, and electronic devices. Since microcontroller projects result in physical creations, they provide an engaging context for students to develop design and programming skills. Moreover, these projects foster abilities that are critical for success in IT careers, requiring creativity, analytical thinking, and teamwork—not just basic IT skills. The project partners are uniquely qualified to implement the proposed program, combining expertise in educational microcontroller technology with extensive experience in delivering enrichment programs for underserved youth.

In terms of broader impacts, the iCODE project has the potential to transform the usage of computer labs in schools and community centers across the country, where after-school hours are often devoted to instant messaging, downloading media files, and video gaming. Accessible from any Java-enabled web browser, the iCODE system offers an engaging, IT-intensive alternative to these activities, providing young people with all the resources they need to design microcontroller-based systems, share code files, exchange project ideas, and connect with university students and IT professionals over the Internet.

RESEARCH QUESTIONS
The iCODE project’s formative evaluation focuses on program processes. GRG and the iCODE team are beginning to examine how the program implementation proceeds and the extent to which the program is implemented as planned. The goal of the summative evaluation is to assess the influence of the program on participating students’ IT attitudes, career aspirations, and skills. Following are the main research questions corresponding to these parts of the program evaluation.

Formative evaluation research questions
1. How is the project implemented across various sites, in Boston and Lowell, and what modifications were made to the planned activities?
2. What successes and challenges were experienced regarding site recruitment and retention? What proportion of recruited students is from racial minority groups and/or from low-income households? What proportion of sites and/or students continues for a second and third year of participation?
3. To what extent do educators perceive the iCODE materials and delivery system to be effective and of high quality? How can the materials and delivery system be improved?
4. What program components were perceived by educators and participants as most and least effective?
5. What lessons can be learned to improve and/or streamline project implementation?

Summative evaluation research questions
Goal #1: Enhance participating students’ technology fluency.
1. To what extent does participation in iCODE change participating students’ engineering and programming skills, and workforce skills (e.g., teamwork, problem solving)?
2. To what program components do students and educators primarily attribute gains in skill?

Goal #2: Increase awareness among participating students about educational and career opportunities in IT and STEM.
3. How effective are the in-person visits and on-line resources in increasing participants’ awareness of educational and career opportunities in IT and STEM?
4. To what extent do participants’ attitudes about STEM subjects and their aspirations for future IT educational and career endeavors change as a result of program involvement?

Goal #3: Connect participating students to a community of like-minded peers and adults.
5. To what extent do students feel connected to a larger IT community, through program involvement? How effective are in-person interactions with undergraduate mentors, Internet-based interactions with industry mentors, and the use of a national invention database for developing this sense of community?
6. What are the perceptions about the project’s success among educators and mentors? What are their perceptions about student gains?
KEY PROGRAM ELEMENTS
The iCODE project is made up of several activities. Each participating student attended approximately 25 after-
school sessions (two per week), two career events, two design exhibitions/competitions, and a week-long summer
camp on a UMass campus in Boston or Lowell—a total of 120 contact hours annually.

Teacher Training
Each iCODE site was run by an educator from the partner site, with assistance from an undergraduate mentor, using
the design challenges and other resources available on the iCODE system. Educators were selected based upon past
experience with facilitating engineering and design experiences. Some of the educators had been instructors at
UMass Lowell’s highly successful, two-week Design Camp for middle and high school students. Other educators
received training from Machine Science during previous projects. Prior to Year One activities, educators received
minimal orientation to the specific modules, since many of them had used similar modules in their previous
experiences.

After-school program
Every partner site ran a weekly after-school program that offered IT-intensive, hands-on activities for 10
participants. In the Lowell classrooms, the students created a “disco ball” motion-and-lights display and a robotic
pet. The engineering techniques that students learned through the design and creation of these projects included:

• Using equipment such as servo motors, LEDs, relay switches & special output devices/voice controllers,
• Wiring output devices, switches, and sensors
• Programming actions into their models

In the Boston classrooms, the students wired advanced microcontroller circuits and built robots that competed in a
“Sumo robot” contest. The engineering techniques that students learned through the design and creation of these
robots included:

• Using sensors to see the other robots and the edge of the playing field
• Making mechanical tradeoffs to make their robot harder to push over
• Programming their robots to operate reliably

Many sessions begin with an instructor orientation of the concepts, engineering and design skills, and/or tool-use
and safety concepts being introduced. These “mini-lessons” helped to orient the students to the design problem at
hand and helped the teacher to informally assess what the students needed to know to move forward. During the
remainder of the session, the educator and undergraduate mentor acted as engineering and design “coaches,” helping
students work through their design struggles by having them articulate what problem they were facing, how they had
gone about solving the problem, and by providing prompts about what they might try next. In addition, an educator
or mentor might prompt a student to talk with another student to help them get ideas about how to move forward.
Collaboration was encouraged and valued during the design process. In addition, each of the 10-week sessions
allowed time for students to share and test ideas, as well as time to critique designs and offer possible solutions to
one another.

Summer Camps
The Year One iCODE experience culminated in week-long camps where students from the year-long sessions got
the opportunity to work with their teachers and mentors at University of Massachusetts campuses in Boston and
Lowell. These sessions gave campers the opportunity to take their IT skills and creative abilities to the next level,
completing collaborative projects of their own design. Modeled on UMass Lowell’s DesignCamp program, the
cohort sizes were small, which provided a workable teacher to student ratio. Each iCODE camp included three visits
to university research labs, affording campers the opportunity to see real world applications of IT and STEM.

As a culminating activity, on the final day of each camp, the parents of each camper were invited to a design show
of their child’s projects. The design show featured the work of iCODE students, as well as that of other design
students, and allowed participants to show their design, discuss what their design problem was and how they went
about tackling the problem, as well as demonstrate how their project worked. This interactive session also provided
students with a chance to answer questions and provide some insight about what worked with their design, what they
might do differently next time, and what type of engineering and design problems they might want to tackle in the
future.

**YEAR 1 EVALUATION ACTIVITIES**

In the first year of the project the following data collection procedures were carried out by GRG to examine iCODE implementation and to relate program processes to outcomes.

**Student pre-post surveys**

Students completed pre-surveys at the beginning of the spring semester in early January 2007 and post surveys at the end of May 2007. These surveys focused on the student’s attitudes towards STEM courses and careers, their educational and career aspirations, and their feelings of connectedness to a larger STEM community.

Closed- and open-ended questions included in the surveys addressed the following areas:

- Background information (pre-survey only): demographic information (e.g., age, gender, race/ethnicity), information about their home life (e.g., parents’ educational level and occupation), grades received the previous semester, how challenging they found their prior STEM classes, and extracurricular involvement (e.g., participation in programs/clubs/activities, jobs, volunteer work).
- IT and STEM attitudes: interest in and attitudes about IT, STEM, and other iCODE content areas; perceptions about the relevance of learning IT skills; and perceptions about their own abilities in IT.
- Education and career plans: educational and career aspirations, knowledge about the necessary preparation for an IT career (e.g., years and type of education), plans for high school courses, and awareness of IT, STEM, and research jobs and professions.
- Awareness of IT tools: IT tools they already use, awareness of various tools used in the iCODE program.
- Program-related information: students’ expectations of the program (pre-survey only) and ratings of various aspects of the program (post-surveys only).

**Site Visits**

The iCODE team and GRG evaluators designed observation protocols to conduct observations at two program sites in Boston and in Lowell during the first iCODE year. The key purpose of these site visits was to address more comprehensively the process goals of the evaluation and to see the curriculum “in action.”

Included in these site visits were interviews with iCODE educators to learn how the observed sessions resembled or differed from prior sessions, and to discuss in more detail the effectiveness of program components and features for their particular group of youth. In addition, researchers tried to gauge the effectiveness of educator training and to collect suggestions for improving training for future educator cohorts.

**Summer camp assessment portfolios**

iCODE summer camp educators administered open-ended reflections to students at appropriate intervals during the summer camp (i.e., timed to correspond to the summer camp activities and content). These questions focused on the processes underlying the building projects that the students undertook during the camp, processes such as conceptualizing problems that require solutions, designing, building, and testing solutions, and working in teams.

**Summer camp student surveys**

A one-page survey was administered to the students at the end of the summer camp. The questions on this survey focused specifically on student experiences and learning.

**End of the year survey of iCODE Educators**

At the end of the summer camp, surveys were administered to all iCODE educators to assess program implementation to date. These surveys collected information regarding the number of students involved, the extent and duration of their participation, the type of activities conducted, and the collaborative and applied nature of their activities. Educators’ feedback about program implementation, including challenges they encountered and suggestions for modifications, was collected in order to inform on-going program improvements. Specific feedback about the iCODE materials and delivery system was collected, in addition to feedback on how well the translation of these materials into hands-on projects worked for their students. Finally, educator surveys included assessment of their perception of student gains.

**YEAR 1 FINDINGS**
Based on the extensive data collected from the various sources in the first year of iCODE, the following conclusions were made:

1. iCODE Holds High Appeal Among the Participating Students and Educators

Overall, the iCODE project seemed to have high appeal among the students. The students enjoyed working with computers, learning to write programs, building robots, and participating in competitions. The educators enjoyed learning engineering concepts themselves and imparting those to the students.

While educators chosen for the program had some experience with engineering and design instruction, some felt that they learned the most about how to conduct open-ended design sessions during the summer collaboration with project designers. One teacher remarked:

*I think every teacher benefits by seeing how other teachers approach and interact with the curriculum. It was an ideal opportunity to work on more complicated projects because the student – teacher ratio was low. I also think in that environment (several teachers) there was plenty of opportunities to disagree but that didn’t really happen. Finally, it gave me an opportunity to focus on [a project PI] and what he saw as important to the program. Up to that point I was sort of on my own to interpret the key ideas. It was beneficial to have him in there as his guidance is probably why there were no disagreements amongst the instructional staff.*

Another aspect of instruction that educators thought might need some additional attention with was team teaching. Most of the educators in this program are regular classroom teachers, with limited opportunities to collaborate or team-teach. At times, the lead educators were not sure how to direct the undergraduate mentors, while at the same time the mentors, some of whom had a great deal of engineering and design experience, but not as much classroom experience were not sure when to jump in and help. A teacher commented:

*Also, I’ve struggled somewhat to define and maximize how I work together with my [mentor]. Although I expect to be giving directions/instruction to the group as an experienced teacher, I was hoping he would take a more active/visible role for whole group instruction and planning.*

2. The Program Was Successful in Most Areas of Implementation

For the most part, the implementation of the iCODE program unfolded according to the proposed plan. This involved the training of the educators, conducting of the after-school sessions at five different sites, as well as the two-week summer camps at two sites. The program was successful at attracting students from diverse racial backgrounds, a proposed target population for the program. In terms of the gender of the students, there were very few female students compared to male students. The program experienced attrition of students due to changes in the sites enrolled in the program and other competing options for after-school activities.

3. Students Reported Improved Programming and Workforce Skills

A majority of the students reported that the program helped to increase their understanding of computer programming and of electronic devices. The summer camp was also successful at increasing student understanding of certain specific programming skills related to the products they created. Preliminary analyses of the portfolios used for the embedded assessment also indicated a gain in knowledge of science and engineering processes by the end of the summer camp.

4. Certain Program Components, Such As Hands-On Training, Were Very Successful With Students

The educators identified several areas of the program that were effective. The components identified as most effective were:

- Online programming: The students received adequate assistance from the online programming portal to build their project. They were able to follow the instructions of online guides and were able to load code onto their projects.
- Hands-on activities: According to the educators, the unique approach that iCODE used to introduce engineering and design skills to students (using hands-on curriculum with online programming component) was the biggest success of the program. The program was designed so that students were introduced to basic concepts and skills, upon which they gradually built until moving toward more open-ended activities. Educators reported that iCODE project materials were well-designed and that students enjoyed working on
the projects. In the words of an educator:

I enjoyed watching the students work on open-ended projects and applying math and science skills to hands-on project. Money and resources prohibit this form of teaching on a regular basis but, in my opinion, it is how math and science should be taught daily.

- Cooperative learning: The design of the program was such that students had ample opportunities to collaborate in small and large groups, which lead to a sense of community between students, mentors, and educators.
- Summer camp: Educators reported that the increased contact time during summer sessions increased students’ engineering knowledge and skills to a large extent.

Educators also described aspects of the program that were not as successful in implementation:

- Lack of adequate practice in building quantitative and measurement skills: Educators felt that increased focus in developing these skills would benefit future cohorts.
- Lack of engagement in research and exploration: Students might have benefited from having more time researching and exploring designs before and during completion of their own projects.
- Community building between students and engineers and inventors needs to be developed more fully.

YEARS 2 AND 3: NEXT STEPS
Based on the Year 1 findings, the following steps are being considered as iCODE moves into its second year.

1. Modifying Educator Training
The educators who participated in Year 1 of iCODE were chosen because they all had some experience with engineering and design activities with middle and high school students. For this reason, they received minimal training before the project began. Program developers kept close contact with educators during the project, which made it possible to help individuals when needed, but during Years 2 and 3 more systematic educator training will occur. This will serve several purposes:

- It will allow experts to delve more deeply into content and concepts that educators will present to students. This way, the educators will be better equipped to answer student questions and address their programming difficulties.
- The type of teaching which occurs in engineering and design experiences can be different than what happens in traditional classrooms. Increased training will afford a chance to introduce educators to the philosophy of teaching and assessment which program developers hope to promote.
- There may be an attempt to increase the resources made available for educators once the program has begun, such as creating an online educational module for continued assistance to them.

2. Improving Online Communication
iCode will attempt to establish an improved online support system for students. This may include an online forum or an online blog for students, which can be used as a discussion board to help troubleshoot programming issues that students are likely to encounter. The online modules can be made more user-friendly by using more diagrams and visual aids to access information in them.

3. Increase Opportunities for Community Building
Educators reported having extremely positive team-teaching experience with their university mentors. At present each site has one undergraduate student mentor, but there will be some consideration given to whether additional mentors should be added to sites and possibly make their services available through the student or educator online modules.

SUMMARY
The collaborative nature of the projects was something that was also beneficial to students, but summer camp experience allowed iCODE educators and project leaders to learn from each other. Educators were able to ask questions of project leaders, they could watch how they interacted with students, and observe how project goals were achieved. Project leaders learned how instructional modules work in a real classroom setting, they learned about assessment and materials management, as well as the barriers that classroom educators face when trying to
implement engineering and design instruction. In addition, project leaders learned about the benefits and challenges of the educator/mentor team-teaching experience. These findings will be helpful in designing collaborative professional development experiences for educators, university mentors, and project leaders in Years 2 and 3.

Year 1 was a pilot year for the iCODE project and much was learned about how to create successful hands-on and materials-rich engineering and design activities for secondary students in urban areas. There was evidence that students were enthused about using the materials, that they maintained positive attitudes about STEM fields, and that they were able to build content-knowledge and design thinking skills. With knowledge of how to improve professional development experiences for iCODE educators, project leaders are confident that Years 2 and 3 will provide beneficial engineering and design experiences for secondary students.

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