

## **2006-1086: DESIGN AND EVALUATION OF INNOWORKS: A PORTABLE, INTERDISCIPLINARY SCIENCE AND ENGINEERING PROGRAM BY VOLUNTEER COLLEGE STUDENTS FOR MIDDLE SCHOOL YOUTH FROM UNDERPRIVILEGED BACKGROUNDS**

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# **Design and Evaluation of *InnoWorks*: A Portable, Interdisciplinary Science and Engineering Program by Volunteer College Students for Middle School Youth from Underprivileged Backgrounds**

## **Introduction**

InnoWorks is an innovative science and engineering program designed by volunteer college undergraduates for middle-school students from disadvantaged backgrounds, the flagship program of United InnoWorks Academy, a 501(c)(3) non-profit educational organization founded in 2003. The primary goals of InnoWorks are to (1) provide underprivileged students with an opportunity to explore the real-world links among science and engineering disciplines, (2) foster teamwork, enthusiasm, and career interests in science and engineering, and (3) use current neuroscience and educational research to develop mentoring, teaching, and learning methods that build student confidence in problem-solving.

The InnoWorks initiative is unique among extracurricular educational programs for several reasons. First, InnoWorks programs are offered entirely free of charge for all students nominated by their schools and community centers. Second, the programs are developed and conducted entirely by volunteer undergraduate students from around the country who are eager to share their passion for science and engineering. Third, InnoWorks curricula are designed to be exceptionally interdisciplinary, which enables students to understand connections among different scientific fields and how they relate to their own lives. Finally, to personalize and improve mentoring and teaching methodologies, InnoWorks develops and evaluates novel adaptations of research by cognitive neuroscientists and educational psychologists.

Currently, there are InnoWorks chapters at Duke University and University of Maryland, College Park (UMCP); three new chapters are being developed at the University of Arizona, Georgetown University, and the University of Pennsylvania for 2006. InnoWorks has completed two successful years of summer programs with over 110 students and 80 volunteer undergraduates. In 2005, the program theme was the human senses and the curriculum was entitled “Making Sense of Senses”. The programs each ran for approximately one week and were divided into sensory themes: Vision, Hearing, Touch, Taste, Smell, and Prediction & Estimation. We used concrete sensory experiences to initiate educational activities modeled on Kolb’s experiential learning cycle.<sup>1</sup> Each theme began with group activities as the primary learning experiences, followed by competitive missions in teams of four students, each with one or two undergraduate mentors. All missions were designed to inspire students to use and extend the knowledge gained from the group-learning activities. Mission topics included robotics, rockets, electronic filters, microscopy, fiber-optics, and crime scene investigation.

Each InnoWorks program is designed to be modular, scalable, and portable for effective national and international application. The program provides an innovative method to bring higher-education expertise to middle-school youth and fosters development of synergistic relationships between universities and communities. Moreover, the program offers a valuable opportunity for undergraduates to become involved in mentoring, teaching, and community outreach. InnoWorks aims to help remedy the national shortfall in future STEM-educated (Science, Technology,

Engineering, and Mathematics) individuals to keep the United States at the forefront of science and engineering innovation.

Herein, we describe the rationale for and structure of the InnoWorks program. We also share our research and evaluation methods along with the resulting data that demonstrate the impact of the program on student interest in and understanding of science and engineering. Finally, we suggest ways in which the InnoWorks program can be expanded nationally and internationally to other institutions.

## **Motivation for InnoWorks**

Compared to its peers, the United States is falling behind in STEM-education. Our overall high-school graduation rate is not even in the top ten among industrialized nations,<sup>2</sup> and American students rank 28<sup>th</sup> in math preparedness and 22<sup>nd</sup> in science preparedness. We are no longer the most college-educated nation and China graduates eight to ten times more engineers each year. As many as fifty percent of black and Hispanic teenagers in the US will never graduate from high school—a substantially higher drop-out rate than that of their white and Asian counterparts.<sup>2</sup> Studies have shown that the so-called achievement gap increases substantially with age,<sup>3,4</sup> suggesting that environmental influences play a major role in the development of this gap. We believe that InnoWorks can increase enthusiasm and confidence about learning science and engineering for youth who otherwise lack access to exciting educational opportunities outside of the classroom. These experiences can help young students gain an awareness and appreciation of these fields and even consider them as potential career paths. A clear scholastic achievement gap creates a substantial need for programs of this nature; indeed, prior research suggests that summer learning opportunities may be the most important difference between students who continue to excel in school and those who steadily fall behind.<sup>5,6</sup>

Although we believe that all students could benefit from the innovative teaching and mentoring methods of our program, we specifically target students that have an interest in learning more about science and engineering, but do not have access to resources for socioeconomic reasons. We believe (and research suggests<sup>7,8</sup>) that this is the population that stands to benefit most from a program like InnoWorks. The reason for working with middle-school students is because we believe that youth of this age have enough maturity and experience to be able to successfully participate in InnoWorks; at the same time, they are young enough to be highly receptive to enrichment opportunities. Moreover, it is in middle-school where most students turn away from math and science.<sup>3,4</sup>

The rationale behind InnoWorks is based on three central principles. First, mentoring is an effective method for inspiring disadvantaged youth to take their educations more seriously. Dubois et al. state, “the strongest empirical basis exists for utilizing mentoring as a preventive intervention with youth whose backgrounds include significant conditions of environmental risk and disadvantage”.<sup>8</sup> Second, youth are full of imagination and enthusiasm, and their creative energies are easier to harness if they are directed towards real-world problems that might positively impact their communities. Hancock et al. came to the conclusion that

Active participation of youth is essential to reenergizing and sustaining the civic spirit of communities. Through skill development in the areas of collaboration and leadership, and the application of these capacities to

meaningful roles in community, youth can play a fundamental role in addressing the social issues that are destined to impact their lives and those of future generations.<sup>9</sup>

Third, InnoWorks is structured on the belief that college-age mentors are ideal role models because of their similarities in age and experience with the middle-school students. Their knowledge of and passion for science and engineering can provide InnoWorks youth with positive influences throughout and beyond the program.

The national call for accountability in education has not generally been applied to supplementary educational programs like InnoWorks. In order to improve the program, meaningful evaluations of the educational innovations and program structure are necessary. Feedback from students and mentors as well as other methods of assessment provide invaluable data with which to improve InnoWorks.

## **Program development**

The InnoWorks: Making Sense of Senses program was developed entirely by volunteer college undergraduates. Details about the impetus, history, structure, pedagogical methods, and curriculum of the program are described elsewhere.<sup>10,11</sup> This section provides an overview of the theory behind and application of the fundamental components of the program.

### *Applying constructivist theory*

A number of recent developments in the fields of cognitive psychology and neuroscience are helping to create a coherent and tangible platform for understanding and testing the nature of learning. More specifically, the theory of *constructivism* provides pragmatic and testable schemes for improving learning, which have been well researched and supported by cognitive scientists,<sup>12-14</sup> though of course not without some dissent.<sup>15</sup> Recent technological developments, such as *magnetic resonance imaging*, have also contributed to this platform by enabling real-time, non-invasive imaging of the brain to clarify how the brain functions when faced with different types of tasks, including learning.<sup>16-18</sup>

For our purposes, there are three components of constructivist theory that had the greatest impact on the structure of the InnoWorks program.<sup>19</sup> First, knowledge must be “constructed” by the learner and incorporated into his or her current understanding. Second, knowledge cannot be transferred intact; thus, higher-order relationships must be recreated. Third, the burden of actually “learning” rests with the learner himself. Mentors who are recruited for the program learn about these ideas and are given pragmatic strategies for managing the students with these ideas in mind. For example, we encouraged the mentors to ask a lot of questions, both to ascertain the students’ knowledge about the subject and also to give students time to think and learn about the material on their own. Also, instead of beginning a topic at a place that seemed natural for us, we started from what the students already knew and built upon that foundation. As educational psychologist David Ausubel said, “The single most important factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.”<sup>18</sup> Our goal was to help the students take ownership of their learning. We helped them when they got stuck, and probed them to think problems through more carefully.

### *Using more of the brain: the experiential learning cycle*

Constructivist ideas and practices have already been successfully integrated with other pedagogical developments, such as learning-styles theories.<sup>20</sup> In particular, Kolb's experiential learning cycle theory has received significant attention from educational researchers.<sup>21,22</sup> This theory argues that learning originates from real-world experiences and involves four essential processes: concrete experience, reflective observation, abstract hypothesis, and active testing.<sup>1</sup> The experiential learning cycle was recently integrated with some general principles of neurobiology, as documented in *The Art of Changing the Brain: Enriching the Practice of Teaching by Exploring the Biology of Learning*, by James Zull.<sup>18</sup> This synthesis is achieved by describing the learning cycle in the context of brain anatomy and physiology. In brief, the human cortical brain can be roughly divided into four regions: sensory cortex, temporal (back) integrative cortex, frontal integrative cortex, and motor cortex. Based on the primary functions of each of these parts, Zull observes that the learning cycle arises naturally from the structure of the brain, with concrete experience being processed by the sensory cortex, reflective observation involving the back integrative cortex, development of new abstract concepts occurring in the frontal integrative cortex, and finally, active testing of the new hypotheses and ideas engaging the motor brain.

One strength of Kolb's experiential learning theory, especially from a teaching perspective, is that it provides a rationale for moving students through different types of related educational tasks in order to enhance understanding. Indeed, Zull argues that a richer learning experience is characterized by involvement of more of the brain; optimally, a student would move through the learning cycle continuously, beginning with raw sensations, reflecting upon them and integrating these new experiences with past knowledge, forming new ideas and hypotheses, and testing these ideas out in the physical world. The cycle continues, because testing one's ideas in the world will provide reactions that serve as further stimuli for the sensory brain.<sup>18</sup>

While this relationship between brain structure and learning theory is quite general, it nonetheless proves useful in guiding the structure of our educational mission. For example, students generally tend to favor some parts of their brain more than other parts in learning. Indeed, Kolb has devised a learning-styles inventory (LSI), which can determine the test-taker's preferred learning style.<sup>1,23</sup> Theoretically, this preference reflects something about the way in which a student would like to learn, but does not limit learning to only one part of the cycle. With this information in hand, it may be possible to determine why some students get excited by and excel at certain aspects of a project, whereas other aspects of the same project seem boring or too difficult. Since effective learning requires *the whole brain*,<sup>18</sup> one goal of InnoWorks is to help students develop those parts of the learning cycle that they are less inclined to use.

It can be a challenge for the teacher and the mentor to help students use more of their brain to produce deeper understanding and retention. Even though constructivist theory posits that the student is the only one who can engage himself in these learning processes, there are many things that teachers and mentors can do to promote learning. Mentors for the InnoWorks program learn about all of these ideas,<sup>10</sup> which help them to more fully appreciate and fulfill their multiple roles—as teachers, peers, disciplinarians, and role models.

### *Other applications of learning theory to program structure*

The desire to learn is intrinsic,<sup>18</sup> but many people still resist the opportunity to learn new things. There is substantial support for the idea that students will naturally learn if they believe that the subject at hand matters in their lives.<sup>18,24-26</sup> As such, InnoWorks begins each new topic with concrete experiences and applications so students can immediately relate the subject to personal experience. In addition, emotions are known to have a dramatic impact on learning.<sup>18</sup> In the context of a classroom, fear and stress are likely to result from a discomfort with the power structure and interpersonal relationships with teachers and peers. Since all executives, mentors, and primary staff members of InnoWorks are college students who have diverse interests, and all have a passion for working with kids, we believe that our program has a distinct advantage over other types of “science-camps” in that the students will likely feel less “threatened” by a staff that is composed of students like themselves. This expectation was borne out by both the 2004 program, “Roboventions”, and the 2005 programs, “Making Sense of Senses”, where several students remarked how this aspect of the program enhanced their enjoyment of InnoWorks.<sup>10</sup>

In terms of motivation and pleasure, there are extrinsic rewards (e.g., prizes) and intrinsic rewards; the latter are intimately associated with the learning itself. InnoWorks provides plenty of extrinsic rewards such as trophies, memorabilia, and other prizes to motivate the youth to work hard and explore everything the program has to offer. We strongly emphasize teamwork, integrity, and dedication through special recognition and awards. Trophies are awarded to all participants who complete the program, with the top-performing teams receiving special prizes. To determine the top teams, points are given throughout the program for performance on competitive missions, group presentations, and reflective questions. Nevertheless, the program is founded on the belief that learning for its own sake (i.e., intrinsic motivation) can be encouraged and nurtured. Our premise is that an understanding of basic science and engineering gives people the freedom to pursue achievement and discovery of uncharted realms; such experiences should contribute to providing the InnoWorks students with enduring intrinsic motivation.

As previously stated, concrete experiences are good starting points for learning new ideas; thus, InnoWorks frequently engages students at this level. But in order to expose students to all parts of the learning cycle, we include periods for deeper reflection. Therefore, after each activity and mission, students are given time to answer a series of reflective questions in their InnoWorks workbooks<sup>11</sup> that are designed to spark synthesis and extension of the knowledge they have gained. Teams are awarded points if every group member completes the questions. In addition, an important aspect of taking ownership of knowledge is evaluation of one's own work. Accordingly, after each mission, we asked the students: “How well did your group cooperate, and did this have an effect on how well your team performed? How did you contribute to or hurt your group's performance? Think about how you can improve personally to help your team even more in future missions.”<sup>10,11</sup>

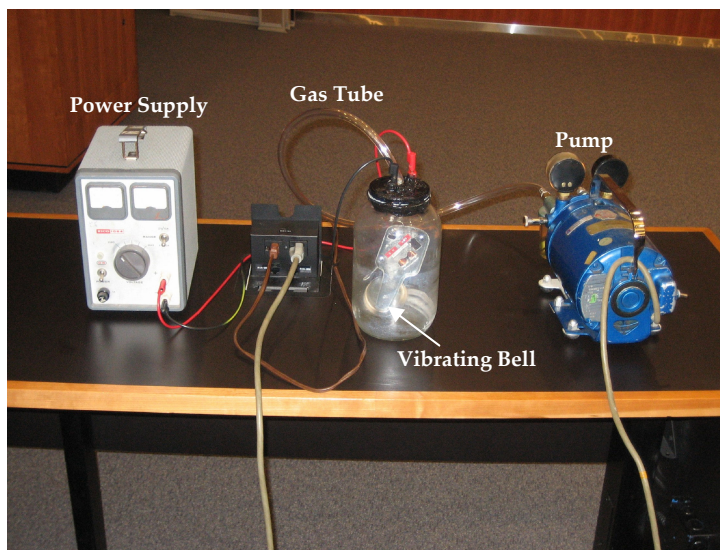
### *Some specific examples of the theoretical basis for the InnoWorks curriculum*

The division of subjects and disciplines is so engrained into our school systems that we find it quite natural to have a Physics class, an English class, a Biology class, etc. In actuality though, most of these divisions are quite artificial, as exemplified by the value of interdisciplinary

collaborations in research, industry, and other sectors of society. To address this issue, InnoWorks stresses interdisciplinary relationships and does not divide program days or projects into traditional school subjects like Chemistry or Psychology. Nevertheless, having themes is useful for program structure and provides a sense of cohesion in the various activities and missions.

Since the “Making Sense of Senses” curriculum emphasized self-directed learning, in accordance with constructivist theory, we did not provide the mentors with definite instructional guidelines. For some mentors, it was probably difficult to operate solely on student feedback of their prior knowledge. However, Zull contends that it is reasonable to assume that since neuronal networks in student brains are related to their own life experiences, sensory experiences in their purest form are a good place to begin.<sup>18</sup> In other words, the brains of both experts and novices exhibit the same sensory capabilities. Effectively teaching and mentoring students requires appreciation of their perspective. All InnoWorks presentations began with concrete sensory experiences, such as things to see, hear, smell, touch, or taste. An interesting instance of “meta-learning” resulted, in which sensory-based learning was used to study the very senses emphasized in this educational theory. A few examples from the curriculum will be useful to illustrate this approach.

We began the Hearing theme by presenting students with the apparatus shown in Figure 1. A vibrating bell was placed inside a sealed transparent jar outfitted with a gas tube. A vacuum pump was used to gradually remove the air from the jar. The students observed this phenomenon with their senses and with no explanations from the presenters except a statement about the function of the vacuum pump. We then asked the students to discuss their observations within their groups and try to explain why the bell could no longer be heard when the air was removed from the jar. Starting from these basic sensory experiences, we moved on to other demonstrations and activities on longitudinal and transverse waves, how our ears transduce longitudinal waves into sounds we hear, sound localization, etc.



**Figure 1.** Picture of Sound of Silence apparatus.<sup>10,11</sup>



The Vision theme began with the simple question, “Can we see in a completely dark room?” Many students believe that humans can see even if it is totally dark. Real-world experiences reinforce these beliefs; for example, when they go to bed and turn off the lights, their eyes slowly adjust to the darkness until they can make out the shapes of objects, but perhaps not their color. Rather than fall prey to the tendency to take student responses at face value and try to erase and replace their ideas, it is more fruitful to realize the underlying basis for students’ prior knowledge.<sup>18,19</sup> More often than not, their understanding is not entirely incorrect, but simply incomplete because of a limited set of experiences from which to extrapolate. After an interesting discussion, the presenters held up a red ball in front of the students and asked several people to describe the ball. We then turned off all of the lights and asked the students at intervals whether they could still see the ball. After a while, many students began to realize that this new sensory experience did not fit in with their previous understanding of vision and became amenable to revising their understanding of how we see. Of course, there were some who were unconvinced and those that even claimed they could still see the ball. The person holding the ball quietly moved from the front to the back of the auditorium, and when we turned on the lights, the students were still looking at the front of the room.

By beginning each theme with engaging sensory experiences, we were able to help the students challenge their own understanding of the world around them. This technique made the students more open to becoming critically involved in the interdisciplinary topics, activities, and missions that followed.

### **Program structure**

The InnoWorks program consisted of three different types of activities: interactive presentations and mixed-team learning activities, team-building activities, and fast-paced competitive missions. Students worked in teams of four with one or two mentors. Each theme (e.g., Hearing, Vision, etc.) began with the students engaging in hands-on, sensory-based presentations and group activities. Since we designed the missions for team competition, the group activities involved cooperative pairing between different teams to increase interactions among students. During the midday break, we provided free lunches and drinks to all participants, mentors, and staff. To develop strong friendships and collaborative trust, team-building activities such as *capture the flag* and *wiffleball* followed lunch.

In the afternoon, we briefed everyone on the objectives and scoring rubrics for two missions. For each of the two missions, we randomly selected two teams to give a capstone, five-minute PowerPoint™ presentation of their approach and solution to their peers, staff, and mentors. The selected teams also discussed the reflective questions that accompanied the mission. The goal of the presentations was to develop the students’ skills in communicating complex ideas to other people.

The missions challenged student teams to develop strategies for solving difficult problems, then actively implement and test their ideas. Missions were fast-paced and relatively specific in the task required of the students. Typical mission problems fell into one of the following categories: (1) follow instructions to set up a phenomenon and explain the physical basis for it as accurately as possible, (2) develop a plan to solve a problem given certain constraints (no actual

implementation), or (3) use a given set of materials to solve a problem, which may require manipulating materials to discover some scientific results or engineering a final device/product. In missions that involved building, the emphasis was on creativity and resourcefulness rather than tedious construction.

We used two different program layouts for the Duke (August 3-10, 2005) and Maryland (August 22-26, 2005) programs, as shown in Figure 2. Each day began at 9:00am and ended at 5:00pm. We provided bus transportation for the students to and from the program at no charge. A representative daily schedule is given in Figure 3. Staff and mentors were required to sign in at the Information Desk by 8:30am. At the end of each day after cleanup, all staff members and mentors convened for a mandatory meeting to discuss any issues that needed to be resolved, potential improvements, and the preparation plan for the next day.

Mon	Tues	Wed	Thurs	Fri	Sat
		Day 1: Foundation	Day 2: Hearing	Day 3: Prediction and Estimation	Field Day/Barbecue
Day 4: Touch, Smell, Taste	Day 5: Vision I	Day 6: Vision II and Open House			

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Mon	Tues	Wed	Thurs	Fri	Sat
Day 1: Foundation	Day 2: Touch, Smell, Taste / Prediction & Estimation I	Day 3: Prediction & Estimation II / Hearing I	Day 4: Hearing II / Vision I	Day 5: Vision II and Open House	

**Figure 2.** (Top) Schedule for 2005 InnoWorks Duke. (Bottom) Schedule for 2005 InnoWorks Maryland.

9:00 AM	Arrival; Introduction to Sensory Theme of the Day
9:30 AM	Group activities
12:00 PM	Lunchtime
12:30 PM	Team-building activity
1:10 PM	Mission Briefings
1:40 PM	Mission #1
2:30 PM	Reflection Questions
2:40 PM	Mission #2
3:30 PM	Reflection Questions
3:40 PM	Preparation for Presentations
4:15 PM	Capstone presentations for Mission #1 and Mission #2
4:45 PM	Students write in Log
4:55 PM	Concluding comments and outlook for next day
5:00 PM	Dismissal

**Figure 3.** General itinerary. Not applicable to foundation day or field day/barbecue. The final day was an open house and the award ceremony was held between 5:00 - 5:30 PM.

### *Detailed description of the Vision theme*

In the following paragraphs, we describe the structure of the Vision theme that was conducted over two days. The complete “Making Sense of Senses” curriculum is detailed elsewhere.<sup>10,11</sup>

After learning about the anatomy and operation of the eye, InnoWorks participants did several group activities related to nuances in vision, such as the visual cocktail effect, central vs. peripheral vision, the blind spot, visual adaptation, afterimages, Benham’s disk, and opposite colors. We explained the wavelength dependence of scattering and refraction with a prism and then asked students to explain the basis of a simple demonstration illustrating why the sky is blue and the sunset red. We paired teams for a series of optics stations, including total internal reflection in JELL-O, mirrors and reflection, making a Pyrex™ beaker disappear by submersing it in Wesson™ vegetable oil, a water-fountain “fiber-optic” cable that can transmit a laser beam, and examination of cheek cells and termite guts with light microscopes.

There were two missions for the Vision theme. The first was entitled “Fiber Optic Communication”. Teams were asked to develop a code for the numerical digits and English letters using laser pulses that could be transmitted through an optical fiber cable. After the code was finished, teams divided into a transmitting pair and a receiving pair. The transmitting pair had access to a laser pen and the open end of the optical fiber cable on one side of a barrier. The judge gave the transmitting pair a secret message to transmit. On the other side of the barrier, the receiving pair watched a light emitting diode (LED) circuit that would light up with each laser pulse, and they recorded the signals. The receiving pair then had to decode the message and submit it for scoring. This mission utilized fiber optics and total internal reflection, both of which were explored in the morning activities; also, it required students to think about the encoding and decoding process. We asked students to come up with attributes of a “good” encoding scheme based on their experiences during the mission. Why are almost all computer and communication systems based on digital encoding (off or on, 0 or 1) instead of analog encoding (any value within a range)? As we had predicted, the teams that encoded letters and numbers with varying pulse lengths did not have as much success as teams that used a binary encoding scheme.

For the second mission, “Autonomous Radioactive Waste Disposal Robot”, the following briefing was given to the students:

The trophy robber that you brought to justice in the CSI mission has not given up on foiling the program’s plans to reward the InnoWorkers with trophies. The robber has gotten access to radioactive chemicals and plans to contaminate the trophies so that they cannot be awarded. We have identified the location of these chemicals, but they are too dangerous for a human to handle. The car designers at InnoMobiles, Inc. need your help to develop a self-driving car that can transport the chemicals to a remote dump site for disposal. The car must first follow a black road on white surroundings to the entrance of a maze, navigate to the center of the maze, and dump the radioactive chemicals upon “seeing” a light. This job has been entrusted to you and your fellow InnoWorkers. The trophies are counting on you!

Teams were given pre-organized kits with Lego Mindstorms™ components and their laptops were pre-loaded with the Robotics Invention System™ 2.0. On the Foundation Day at the beginning of the program, a “Roverbot” practice mission was completed to familiarize teams with the robotics kits and associated programming interface. We provided a detailed set of mission objectives, scoring rubric, and “fees” for purchasing additional parts, testing on the

apparatus used for judging, and borrowing robotics books. One of the most successful elements of this mission was its incremental nature; all teams were able to get some of the mission points because it was divided into three distinct phases: (1) following a road, (2) navigating a maze, and (3) activating a dump mechanism upon sensing light.

Students' preferred learning styles were conspicuously manifested in this mission. While some students just wanted to play with Lego™ pieces, others were engrossed by how the computer program can cause the robot to behave “intelligently”, and still others were quietly brainstorming creative, though often far-fetched, design ideas. Overall, the computer programming was the most difficult task for the largest number of students. One useful pedagogical method we discovered was to walk students through algorithm development by pretending we were robots. For example, one solution to the maze portion of the mission was to put two touch sensors on either side of the front bumper. How do we program the touch sensors? First, a mentor or staff member would walk in a line diagonal to a wall until his right “bumper” hit the wall. What should the “robot” do? Many students said to turn left, but the “robot” was still trying to move forward and scraped against the wall... Most students rethought their plan and quickly decided that the robot should first back up and then turn left. Acting out the robot's behavior turned out to be an effective way of helping them understand how to design algorithms.

After the mission, we asked students a series of reflective questions to help them apply what they had learned. For example,

The idea of a self-driving car has been around almost as long as cars. What are some complications in an actual driving environment (e.g., highway) that make designing a safe self-driving car difficult?

Do you think people will ever be able to make robots that are as smart as humans? Why or why not?

How are humans different from robots? What makes us unique?

### *Student nominations*

We used a nomination system to select students because we did not want to turn away anyone. Principals, counselors, teachers, and community leaders were contacted and given allocations to select the students they felt were most likely to benefit from InnoWorks. Because of our limited number of student slots, we told them that we were looking for middle-school students that did not have access to summer programs like InnoWorks because of socioeconomic reasons but perhaps have shown some curiosity towards science and engineering. We defined underprivileged status by the qualification for free or reduced-cost school lunches.

The majority of students at the Duke InnoWorks program attended Chewning Middle School (CMS) in Durham, NC. In the spring semester, several InnoWorks volunteers visited CMS during a Science, Social Studies, and Humanities Expo and discussed the program with students, parents, teachers, and the principal. Students were transported between Duke and CMS using a bus provided by CMS. We also visited community centers and worked with the directors there to recruit students.

For the Maryland InnoWorks program, we collaborated with the Montgomery County Department of Recreation (MCDR) to recruit students. The MCDR was responsible for nominating and transporting students.

### *Mentor and staff recruitment*

InnoWorks executives were primarily recruited on a personal basis by the founder of InnoWorks. This core leadership group then recruited new members, established chapters at Duke and UMCP as chartered university organizations, and created and advertised an online application form to recruit mentors and staff. Over eighty undergraduate volunteers have devoted themselves to InnoWorks over the past two years; they were not compensated for their time or efforts.

There were forty-four student participants, twelve mentors, and eighteen staff members for the Duke program and thirty student participants, fourteen mentors, and twenty staff members for the Maryland program. There were eleven teams in the Duke program and seven teams in the Maryland program. With the exception of one team, each Duke group had one mentor while the Maryland teams had two mentors each. Most mentors were majors in science and engineering disciplines, and many were double or triple majors with other subjects such as history, political science, economics, and languages. The majority of mentors and staff did not have formal training in teaching, but many had prior experience as mentors in summer camps and tutoring programs.

### *National Training Summit*

We held the first annual National Training Summit (NTS) at Duke University from July 29-31, 2005. Mentors and staff members for the Duke and Maryland programs, as well as other interested undergraduates from universities such as Carnegie Mellon University and University of Pennsylvania, participated in the training. We presented the goals and organizational structure of InnoWorks and we discussed their responsibilities to the program and the students. We also presented our unique pedagogical and research methods. Participants picked up materials such as mentor books, research notebooks, name tags, clipboards, schedules, and T-shirts. Everyone completed a dry run of all activities and missions and we made modifications as needed.

### **Mentor research and benefits**

In addition to an evaluation of student gains and opinions of the InnoWorks program, we engaged mentors as researchers and are evaluating the value of the program to the mentors themselves. We briefly describe these other elements of the research and evaluation effort below.

### *Mentors as researchers*

Since the mentors had the closest interactions with the InnoWorks students, we believed that they were in the best position to ask and potentially answer some interesting questions about teaching and learning. While there are many interesting research questions that the mentors might have considered, we asked the mentors to focus on the results of the Kolb Learning Style Inventory (LSI), which was administered to the middle-school students at both the beginning and

the end of the program. The specific research questions and the outcomes are detailed elsewhere.<sup>27</sup> To facilitate this research, we gave each of the mentors their own research notebooks and asked them to write daily entries. The program director periodically checked the entries for completion. In addition, mentors wrote 3000-word reports synthesizing their research during the program.

The purpose of these investigations was to engage the mentors in the practice of teaching and learning in a deeper way by asking them to formally design their research effort and describe how they intend to perform their investigations, especially in the face of their overarching duties as mentors to their students. The collective efforts of the mentors provided a powerful analysis of the ideas we applied to the InnoWorks program. Most of the mentors found that by engaging in their role as educational researchers, their mentoring experience became substantially more interesting, fulfilling and effective. Similar efforts in other contexts have shown that mentors and educators find this type of exercise very valuable (Bissell, A.N., Unpub. data). The continued viability of the InnoWorks model will depend on this type of ongoing evaluation of its structure, especially as it spreads to other campuses and involves new staff and sponsors.

### *Mentor gains*

Of the twenty-four mentors participating in the 2005 Duke and MD programs, twelve were males and twelve were females. One of the goals of InnoWorks was to analyze program impacts on the mentors themselves, including what they learned and enjoyed, how well they understood and took to the tasks they performed, and whether they experienced any conceptual changes in their notions of teaching and learning. Many people find teaching to be transformative, and they find that teaching truly illustrates their own depth of knowledge and level of comfort with their understanding of material. We expected that InnoWorks mentors would be similarly affected, even though the overall structure of the program is less formal than a “typical” teaching assignment.

We are evaluating mentor gains mostly on the basis of the regular notebook entries that the mentors compiled during the program. These entries provided the means for mentors to self-reflect, log ideas and concerns, and keep track of things during the course of the program. It was stressed to the mentors that these research efforts were not actually formal teaching evaluations; in other words, we were not primarily interested in evaluating their *performances* as teachers. Rather, we saw the mentors as students of a sort themselves, and we wanted to know if they gained any tangible benefits by being mentors in the InnoWorks program. Towards this end, mentors were asked to complete an extensive exit survey at the conclusion of the program. An analysis of mentor gains and training (NTS) is provided elsewhere.<sup>28</sup>

## **Program outcomes**

### *Overview*

Both the Duke and Maryland “Making Sense of Senses” programs were successfully implemented. We determined which activities and missions worked especially well and which ones could be improved. We are currently revisiting the “Making Sense of Senses” curriculum

and expect to publish a revised second edition of the complete manual and student workbook in Spring 2006. For the most part, behavior problems were not a major issue because we had enough mentors and staff to address any situation before it escalated. The overall activities-missions structure as well as the points-trophies system kept the students interested and engaged throughout the programs.

For the Maryland program, two college undergraduate mentors supervised groups of four middle school kids while only one mentor supervised each group for the Duke program (with one exception). While no significant increase in group efficiency or speed was observed at Maryland relative to Duke, there were several mentors that were involved with both programs who said having an extra mentor made it easier to deal with behavior problems because one mentor could take a problematic group member aside while the other mentor kept the rest of the group moving forward.

The Maryland program was five days long while the Duke program lasted seven days. However, the Duke program was the first time we ran the “Making Sense of Senses” curriculum, so having more time to work with the participants proved to be very helpful. There were no significant difficulties at Duke except for some missing robotics pieces on the first (Foundation) day. Before the Maryland program, we carefully checked the kits that we provided to teams so the robotics training mission was more streamlined the second time around. Furthermore, we found at Duke that starting with the Hearing theme was not ideal because it involved complex concepts such as waves, frequency filtering, and electrical circuits. Instead, we thought that the Touch, Taste, and Smell theme would be better suited to begin the program (after the Foundation Day) because it involved fewer abstract concepts and the missions had greater attention-grabbing power. Thus, we rearranged the schedule and second printing of books for the Maryland program and the feedback was positive.

At Duke, we had a weekend and barbecue/field day in the middle of the camp, whereas the Maryland program ran for five straight days. Several mentors and staff members at both programs commented that this “fun day” at Duke was effective in letting everyone recharge between the two parts of the program. Also, the barbecue/field day gave us a chance to meet the students’ families. Our major sponsors were recognized and invited to table at the event.

The Foundation Day was crucial for getting students oriented to the structure of InnoWorks; therefore, we felt compelled to keep that first day intact in the Maryland program. The tradeoff was that we had to divide several of the other themes across two days, creating a slight disruption of the morning activities–afternoon missions structure. The feedback we received indicated that the Duke schedule was better. In our revisions of the “Making Sense of Senses” curriculum, and in our development of new curricula in the future, we will strive to further increase modularity and scalability so that various themes can be easily rearranged as units and expanded and contracted depending on a particular program’s needs.

### **Evaluation of student backgrounds and gains for both InnoWorks programs**

To determine student gains from the program, quantify the success of the program in generating interest and enthusiasm in science and engineering, and identify areas of potential improvement,

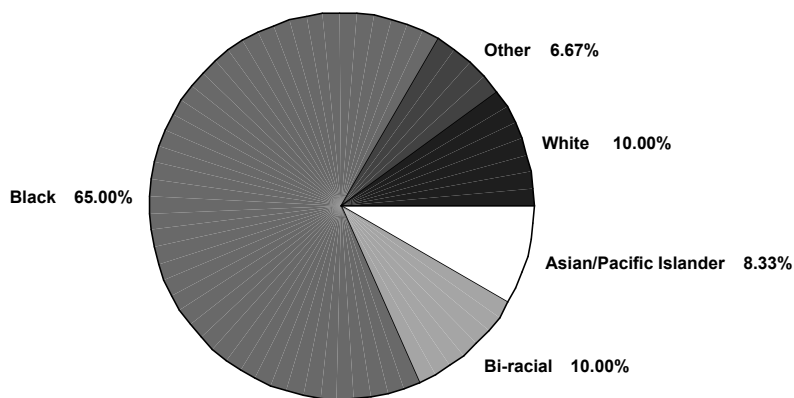
pre- and post-surveys were electronically administered to students on the first and last days of the program, respectively. Students completed the surveys in a computer lab.

These data are based on the survey responses of 60 students (31 females, 29 males) that completed both the pre-survey and post-survey. Students that provided incomplete survey responses were not included in the analysis. During administration of the surveys, we told students that they should be completely honest with their answers and that there would be no repercussions for negative responses. Furthermore, they were informed that the purpose of the surveys was to help improve the program.

#### *Student backgrounds and attitudes about learning science and engineering*

Figure 4 illustrates the ethnic backgrounds of the students for both programs. The largest group of students described themselves as black (65%). Almost all of the students in the Duke program were black, while there was slightly more ethnic diversity in the Maryland program. Because we recruited primarily through schools for the Duke program versus community centers for the Maryland program, we were better able to obtain participants from underprivileged backgrounds at Duke. In fact, through our conversations with school teachers that nominated students for the Duke program, we found out that most of the students had never been able to attend a summer camp before. Since our criterion for underprivileged status rests on whether a student qualifies for free or reduced-cost lunch at school, information that community centers often do not have, we aim to obtain most of our participants through schools in the future. This goal means that chapters will have to recruit students when school is still in session; the advantage of recruiting at community centers is that they are generally open year-round.

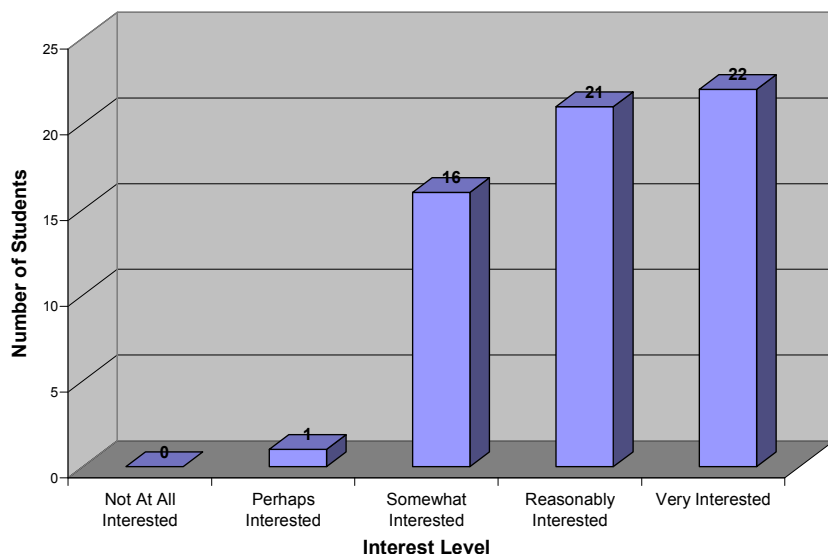
The majority of students (80%) were in middle school, which was our target group. All of the elementary school students were in 5<sup>th</sup> grade and all but two of the seven high school students just graduated middle school and were entering 9<sup>th</sup> grade in Fall 2005. Siblings requesting to participate together were often the reason that some students were outside the ideal age range. The main problem with students being either too young or too old was that the material was not as suitable for them—being too difficult or too easy, respectively. Age-related issues did not seem to cause significant social or collaboration problems. In the future, making sure that all students are in middle-school will be a relatively simple screening process that was not applied strictly this year only because there were still slots available in the programs.



**Figure 4.** Student ethnicity.

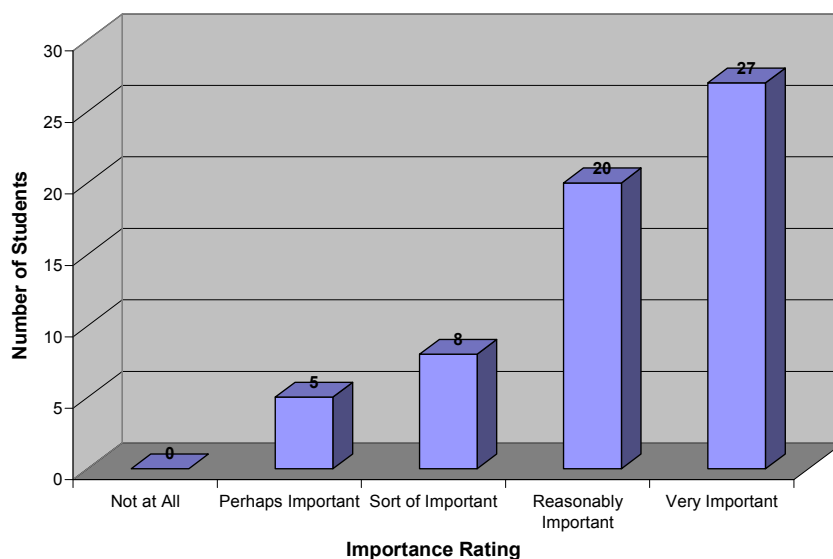


Students rated their interest in science prior to InnoWorks on a range from “Not At All Interested” to “Very Interested”, as shown in Figure 5. All but one student was at least “Somewhat Interested” in science before the program. These data met our expectations since the students should have been nominated based (in part) on their interest in science. Furthermore, research has shown that youth of this age usually profess an interest in science regardless of their ethnic background or gender.<sup>29,30</sup>



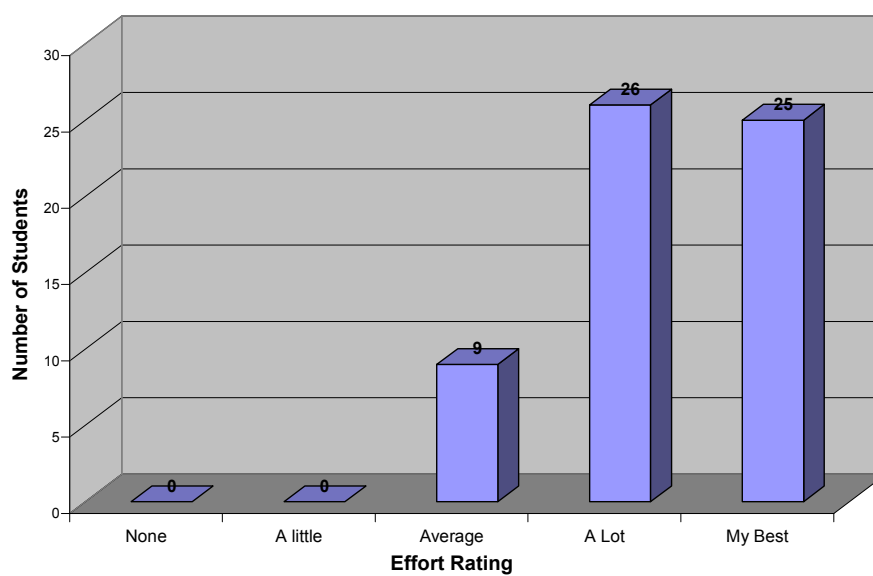
**Figure 5.** Student interest in science prior to InnoWorks.

When asked, “How important do you think science will be in your future?”, more than 75% of the students responded with at least “reasonably important”, as indicated in Figure 6. Only 24 students indicated an interest in a scientific career, suggesting that many students who were not considering scientific careers still believed that science would play a significant role in their lives.



**Figure 6.** Student predictions on the importance of science in their futures.

When asked, “How would you describe the amount of effort you put into school?”, no student responded with less than “average”, as shown in Figure 7. This result was not surprising, since most middle-school students, and African-Americans in particular, exhibit strong self-concept and an interest in academic success.<sup>4</sup> In addition, many young students lack the ability to accurately self-reflect on their own performances. InnoWorks emphasized development of this skill by asking students to critically evaluate their own efforts as part of a team.



**Figure 7.** Self-reported student effort in school.

### *Student feedback and gains*

Over 94% of students said that they would participate in InnoWorks again. Numerous students described their feelings towards InnoWorks:

*“They’re [mentors] really protective and they care about you a lot. I liked science but I didn’t think it would be as fun so I didn’t really pay much attention to it, but now I realize that science is much more than boring.”*

Brittany W, 11  
2005 InnoWorker  
WRAL 5 (CBS) News

*“I’m having a great time, and I’d like to thank all of these great people [InnoWorks mentors and staff] for coming out of their way and putting their lives on hold to be with us young folks. Thank you!”*

Chris T, 13  
2005 InnoWorker  
InnoWorks DVD

*“They’re amazing, really. We can relate to them because they’re going to school and we’re going to school -- we’re all working towards the same goals. They talk to us about college and what we can do in science.”*

Brianne E, 13  
2004 InnoWorker  
Maryland Gazette

*"What is my favorite mission? Only one??...ahh! ... The one where we saw how much bacteria was on our hands. Oh—I wish I could pick more than one! This was a nice camp!"*

Aissia B, 16  
2005 InnoWorker  
InnoWorks DVD

*"The games, the things we do, how we learn how to do everything we need to learn, it's actually cool! I would come back next year."*

*"Yeah, me too!"*

*"Me too!"*

*"Me too!"*

Joseph C and teammates  
2005 InnoWorkers  
Duke News and Communication

*"The camp was great—it was very, very great. These were some nice mentors and all that. It's just a great camp! I will recommend it to other kids."*

Shakela J, 11  
2005 InnoWorker  
InnoWorks DVD

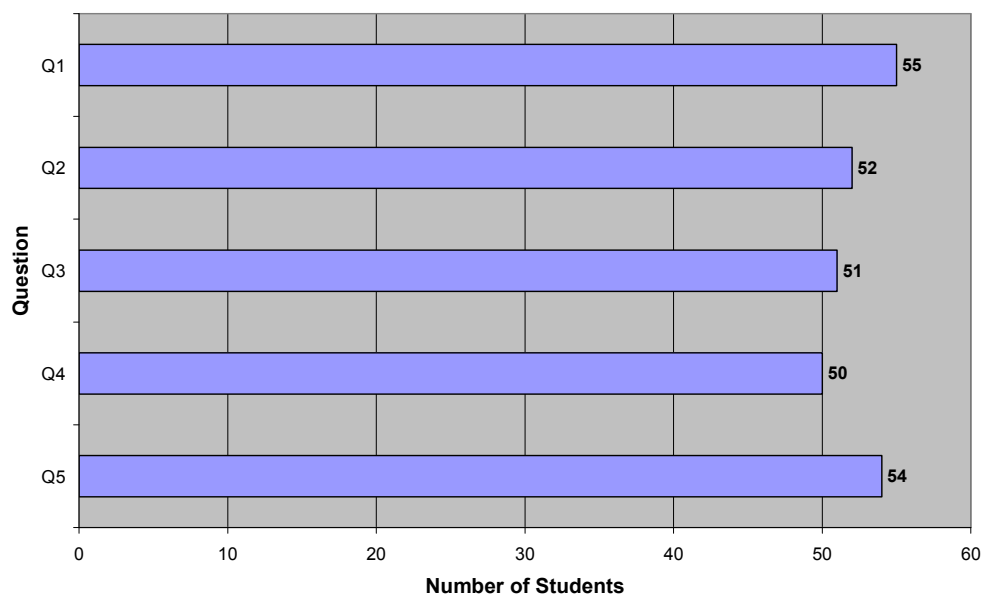
*"Thanks for creating this fantastic opportunity to learn about robotics and the Lego kits. I really enjoyed this class, and further appreciate robotics because of it ... I would definitely do something like this again. So, thanks again for all of your effort and commitment towards making this class educational and fun (and rarely do those two words go together)."*

Brianne E, 13  
2004 InnoWorker  
Letter to InnoWorks Director

We also received numerous cards and letters of appreciation from parents, teachers, and community leaders.

The post-survey included a series of statements that students responded to with answers ranging on a five-point scale from "Strongly Disagree" to "Strongly Agree". These questions were intended to assess student gains from InnoWorks, and are summarized in Figure 8. Clearly, student responses to the program were overwhelmingly positive.

When asked whether the program had changed their feelings towards learning science, 51 (out of 60) students responded that the program made them more interested in learning science. Furthermore, of the 22 students that reported being "Very Interested" in science prior to the program (Figure 6), all but one were even more interested in learning science as a result of the program. This finding suggests that not only was InnoWorks successful in generating greater interest in science among the vast majority of participants, it had an even larger positive impact on the students that came into the program with the greatest interest in becoming future pioneers and leaders in science and engineering.



**Figure 8.** Responses to student gain questions. The number of students indicated for each question are those that agreed or strongly agreed with the statement.

- (Q1) This program helped me understand science better.
- (Q2) Because of this program, I feel better about being able to learn science.
- (Q3) I learned some things in this program that I can use in science class in school.
- (Q4) Because of this program, I think I am more aware of the importance of science in everyday life.
- (Q5) I tell my family/friends about the things we do in this program.

To the question, “Has this program encouraged you to think about taking more science in the future?”, only 38 students responded “yes”. This result suggests that numerous students who enjoyed the program may not associate InnoWorks with their science courses in school. To increase our impact, we will continue to develop ways to link InnoWorks with school so that students understand the importance of their educations for their futures. Towards this end, we have been sharing our ideas and discussing potential collaborations with other programs, such as TASC (Teachers and Scientists Collaborating) (<http://tasc.pratt.duke.edu/>), an NSF-funded math-and-science partnership program based at Duke University, which trains North Carolina teachers to use inquiry-based learning in their classes. We are also developing ideas for an after-school InnoWorks program involving missions that complement the school curriculum.

### Program costs

There is significant flexibility in financing the InnoWorks program with a balance of support through in-kind and monetary contributions from corporate, foundation, university, and private sponsors. As a grassroots program based at universities to benefit local communities, the range of potential benefactors is very broad. Underlying these strategic partnerships is a mutual desire to tackle the STEM shortfall in the US. The primary sponsors for 2005 were Cisco Systems Foundation, GlaxoSmithKline, National Science Foundation, and Duke University. One major advantage of the university-chapter system is that all of the expensive equipment and facilities were loaned to InnoWorks and we expect that such partnerships will continue to be developed as

new chapters are established. Furthermore, there were no personnel costs for the 2005 programs as all staff, mentors, and executives were volunteers.

The remaining program costs fall into the following categories: curriculum materials, NTS, food, mentor and staff housing, program books, awards, publicity and promotional materials, T-shirts, office supplies, and student transportation. Costs will fluctuate depending on the success of local chapters in obtaining local support, but current chapters have had high success in obtaining food and supplies donated by generous, community-minded businesses and vendors.

As described in the “Discussion and future outlook” section, a national office currently under development aims to provide block funding and program materials to support local chapters. This will substantially reduce the amount of funding local chapters need to acquire, giving them more time to concentrate on making their programs great experiences for the students and college volunteers. Even if local chapters end up dealing with some of these costs, the ability to secure funding and support is an important skill for future leaders and entrepreneurs to learn, it gives a greater sense of ownership to the student leaders of the local chapters, and it builds explicit and long-lasting relationships between the college students, the schools, and the community.

### **Discussion and future outlook**

Overall, the first two years of InnoWorks have been highly successful. InnoWorks has been profiled by CBS, NBC, ABC, Duke News & Communication, The Herald Sun, Duke Chronicle, Duke Dialogue, Maryland Gazette, LT Today, DukEngineer Magazine, and is featured on the 2005-2006 Duke Basketball Halftime TV Spot. The students were excited about the program and the questions they were exploring and we believe that many will bring their renewed curiosity with them when they return to school. We aim to continue our contact with students by two primary means: (1) organized events on campus arranged by each chapter (e.g., interesting science and engineering competitions, presentations, and poster sessions), and (2) a web forum through which students can communicate with each other, their mentors, and other staff members, allowing the students to ask questions whenever they need advice or help in academics and otherwise.

Although the InnoWorks program is probably too short to directly impact student grades in school, we are nonetheless tracking the grades of the participants to give us additional information about possible long-term benefits of learning science and engineering in this manner. If we are successful in generating additional opportunities to engage the students outside of the one-week programs, then such analyses will likely prove quite valuable. Ideally, we hope to be able to help participants effectively transfer their new learning tools and dispositions to the school environment and their lives in general. Other extracurricular programs in science have been able to document long-term benefits for participants in the form of higher college graduation rates and pursuit of careers in the sciences,<sup>31</sup> so we are hopeful that InnoWorks will have similar long-term impacts.

We look forward to expanding InnoWorks to the national and international level in the coming years. For 2006, we are developing three new chapters at Georgetown University, the University

of Pennsylvania, and the University of Arizona. We have also received interest from India, the Philippines, France, England, the Bahamas, and Saudi Arabia through personal inquiries and presentations. As the program expands, the organizational model will be two-tiered, where a national office provides support and outreach, while the university-based (local) chapters consist of undergraduate volunteers interfacing directly with the students, schools, and communities. We have already produced high-quality published materials describing the program structure, division of labor, educational research, pedagogical methods, activities, and missions.<sup>10,11</sup> Future plans include: (1) development of “ready-to-go” kits for the activities and missions, (2) improved training materials (e.g., video demonstrations), (3) creation of new curricula (e.g., “Explorations” theme currently under development), (4) integrating InnoWorks into service-learning, K-12 education, and/or community outreach offices in universities, and (5) establishment of service-learning courses for mentor training and perhaps teaching credit for mentors.

The responsibilities of the national office will include: (1) responding to queries for new chapters by sending guidelines and evaluating proposals, (2) disseminating program and training materials such as books, equipment, and training videos, (3) developing and conducting the annual National Mentor and Staff Training Summit, including a significant online component for efficiency, (4) compiling a national newsletter to keep all chapters in communication, (5) making site visits, (6) overseeing development and compilation of new curricula that will be performed at both the local and national level, (7) developing and evaluating the program, and (8) obtaining funding to support local chapters.

Local chapters will be responsible for: (1) communicating with the national staff on needs and progress, (2) writing proposals and raising necessary funding at the local level, (3) recruiting and organizing the staff and mentors to run their program, (4) obtaining and transporting students to and from the program, (5) working with local schools, (6) arranging for the necessary facilities and equipment that cannot be provided by the InnoWorks organization, and (7) developing portions of new curricula that will be synthesized at the national level.

We are currently piloting a training program in the Duke chapter that involves grouping InnoWorks veterans with new InnoWorks volunteers for at least one semester, during which they will learn about the structure and function of the InnoWorks effort. Also, over the next few years, many InnoWorks students will be in high-school and might be able to participate in a junior mentors program for alumni. We believe that such a system will be a lot of fun for everyone involved and will further our goals of perpetuating the InnoWorks mission. As more and more chapters emerge around the country and the world, we plan on establishing regional associations to foster the development of a global InnoWorks family.

InnoWorks represents a new paradigm in grade-school science-education and outreach. A key innovation of the program is the use of undergraduate student volunteers as mentors, lessening the gap in both lifestyle and age between mentors and students and promoting a collaborative working environment. A second key idea is the explicit incorporation of the best theories in the educational research literature to guide the overall structure and purpose of the learning environment. These two elements, combined with the strength of the program materials and the dedication of the staff, give credence to the idea that the InnoWorks model may be able to inject enthusiasm into learning and complement science and engineering education throughout the

country. The United States is not producing enough scientists and engineers, and many of those who are not in scientific disciplines are disinterested, distrusting, or downright hostile to science and the scientific method. A number of studies suggest that a key turning point for interest in science occurs in elementary school, and that impressions and biases formed this early in life can often carry over through the rest of grade school, college, and beyond.<sup>3,4,25</sup> The InnoWorks program, though currently modest in scope, can help to increase scientific interest among our grade-school kids and ultimately build a broader base of support among the general public for scientific research and thinking.

## **Acknowledgements**

This work was supported by Cisco Systems Foundation, GlaxoSmithKline, National Science Foundation under the MSP VIPK16 Grant, Burroughs Wellcome Fund, Duke University, University of Maryland College Park, Experience Based Learning Systems, Inc., Hay Resources Direct, Duke Engineering Student Government, Montgomery County Department of Recreation, Quiznos Sub, York, Burke, and Lee's CPAs, P.A., Biogen IDEC, Kaplan & Sorosky Ltd., and Target Corporation.

We would like to express our gratitude to the following people for their invaluable help and support: Kristina Johnson, Paul Klenk, Spencer Brown, Michael Fuhrer, Kip Cooley, William McNairy, Annette Golonka, John Thomas, Rebecca Small, Linda Broughton, Michelle Tabares, Jeffrey Forbes, Chris Clarke, Kathy Hoffmeier, Billie Wilson, Edward Paradise, Joe Freddoso, Shelvette Adderly, Elaine Rothbauer, Mary Linda Andrews, James Zull, David Kolb, Alice Kolb, Nannerl Keohane, Ian Baucom, Li-Min Lee, and Beth Barak.

The success of the InnoWorks programs would not have been possible without the dedication and hard work of many volunteer executives, mentors, and staff: Vineet Agrawal, Matthew Mian, Daniel Kaplan, William Hwang, Jessica Manson, Jessica Son, Matan Setton, Adam Schmelzer, Melissa Qazi, Melissa Levy, Bilal Aijazi, Tina Tailor, Amrith Krushnakumaar, Gayatri Acharya, Allen Lee, Michael Garcia, Edward Chu, Dinesh Kumar, Kristen Ward, Mimi Zhang, Noah Grosfeld-Katz, Amit Patel, Regina Cheng, Phillip Hwang, Grace Lau, Michael Li, Yuan-Yuan Hwang, Sharad Satsangi, Amit Joshipura, Celine SooHoo, Jessica Chu, Kristina Yee, Joseph Babcock, Lori Hu, John Korman, Jing Luo, Kristen Ward, Kevin Peng, Letty Villa, Judy Chiang, Sara Chung, Kate Bell, Sarah Gingold, Victor Chan, Andrew Kiang, Daniel Kim, Yeelan Ku, Cathy Lin, Mary Ma, Debby Man, Pierce Smith, Alice Tsai, Joanna Tsai, Jeanne Yang, Sam Wen, Nita Amornsiripanitch, Peter Blair, Lisa Richards, Angela Jiang, Amanda Way, Neil Agarwal, Beth Gingold, and Max Powers.

We would like to thank Joseph Babcock for helping revise the earlier drafts of this paper.

The research methods described in this paper were reviewed by the Duke Institutional Review Board and approved as protocol number 1284.

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