Teaching K-12 Engineering using Inquiry-Based Instruction

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Introduction

Since 1999, the Pratt School of Engineering at Duke University has placed 95 undergraduate and 33 graduate Engineering Teaching Fellows in 14 elementary schools and five middle schools in four counties in North Carolina serving 6,500 students. These Fellows assist partnership teachers with the creation and delivery of lessons and activities that integrate meaningful math, science and engineering exercises into all areas of the Standard Course of Study. Based on outcome assessments of training needs for these Teaching Fellows and recommendations from the National Science Education Standards on best practices for teaching K-12 science, the Pratt School of Engineering created the MUSIC Program (Math Understanding through Science Integrated with Curriculum). MUSIC is a GK-12 track 2 program funded by the National Science Foundation. The MUSIC Engineering Teaching Fellows receive intensive and paired teacher/fellow training in inquiry-based instruction. The Pratt School of Engineering, partnered with the North Carolina Department of Public Instruction, the North Carolina Science, Mathematics, and Technology Education Center, GlaxoSmithKline, Progress Energy and nine North Carolina school systems, has also developed a K-8 teacher training initiative known as TASC: Teachers and Scientists Collaborating. TASC will train 7,560 teachers by 2007. Beginning in the fall of 2004, TASC trainers began providing the more intensive, ongoing training for Duke Engineering Teaching Fellows in inquiry-based instruction. This paper describes the evolution of changes made in the Duke Engineering Teaching Fellows (ETFs) training program based on formative and summative evaluation of the last five years of the Duke ETF program, provides a brief definition of inquiry, an overview of outcomes studies of inquiry-based instruction applied to teaching K-12 science and engineering concepts, and describes formative outcomes of our new inquiry-based training program

Brief Outcomes from past Duke Engineering Teaching Fellows Programs

Since 1999, the Duke Engineering Teaching Fellows Program has placed graduate/undergraduate Teaching Fellows in 19 schools in four counties. Fellows provided: assistance/expertise for teachers in design/delivery of hands-on activities integrating science and engineering into the NC Standard Course of Study; “Science Boxes” to collect and answer student questions; and “Science Nights,” “Discovery Days,” and “Win a Day at Duke” contests. Initial bi-annual fellow training workshops for the 1999-2003 Duke-NCSU Engineering Teaching Fellows Program were taught by teachers from partnership schools and covered Bloom’s Taxonomy, learning styles of special-needs children and behavior management but offered only minimal opportunity for Teaching Fellows to experience being in the role of a “student” and immersion in inquiry--based

lessons. Although student and fellow impacts were positive (increased student confidence in science ability, increased student rating of experiencing science as fun, increased student awareness of science in the world around them, increased student engagement/question- asking during Fellows class time) Fellows reported a need for more in-depth training in classroom teaching skills and development of lesson plans.

A second Duke Engineering after-school academic enrichment program, *Techtronics: Hands-on Exploration of Technology in Everyday Life,* partners Duke's Pratt School of Engineering with Rogers-Herr Middle School in Durham, NC. Offered two hours per week, *Techtronics* goals include inspiring a passionate interest in science, engineering and technology by introducing middle school students to four branches of engineering (electrical/computer, biomedical, mechanical, and civil) through hands-on team projects taught by Duke undergraduate and graduate engineering students.

Initial funding by a three-year grant (2001-2004) also produced positive results:

- 120 students served: 67% African American, 50% female
- Student return rate of 50% for 2002-03 and over 70% for 2003-2004
- For the 2003-04 school year, positive student impacts include:
  -76% of students indicate willingness to participate in a similar program again;
  -83% of students report a better understanding of science as a result of the program;
  -68.9% of students report feeling better about being able to learn science and;
  -65% of students indicate more awareness of the importance of science and technology in daily life.

Despite these positive impacts, *Techtronics* Fellows also reported a need for more in-depth training, both in classroom management techniques and in inquiry-based instruction techniques. Additionally, a systematic way to organize and disseminate follow- up lesson plans for classroom teachers at the partnership school would facilitate lasting programmatic assimilation into the school itself.

A third engineering Teaching Fellows program, Math Understanding through the Science of Life (MUSCLE), funded by the GE Foundation Math Excellence Program, partnered the Pratt School of Engineering with Lakewood Elementary School and Rogers-Herr Middle School in Durham, NC. Undergraduate Engineering Teaching Fellows were placed in these two partnership schools 10 hours per week, helping teachers develop and teach lessons and activities that integrate meaningful math and engineering exercises into life sciences. Hands-on projects were used to engage students in creative ways to inspire a passion and curiosity about math, science and technology.

To date the MUSCLE program has served 1,907 students over its three years of operation. From examination of data from the project beginning, the target goal of increasing the End-of-Grade (EOG) math scores by placing Duke Teaching Fellows in these partnership schools was exceeded. For the end of grant year (2003-2004), the target goal of increasing the EOG math scores exceeded the predicted EOG scores for all three grades by 3% for 3rd grade, 12.3% for 4th grade and 20.5% for grade 5. In addition, when 2003-04 EOG math scores were compared with baseline EOG math scores, a stunning increase of 19.7% for grade 3 and 19.1% for grade 5 was

noted from the beginning of the MUSCLE program to the program's completion. Further examination of percent of students eligible to take Algebra by 8th grade from the program's beginning to completion revealed a substantial 20% increase (from 14% for 2000-01 to 34% for 2003-04). Additional positive outcomes associated with the MUSCLE program include the high ratings of Teaching Fellows by their partner teachers (high average ratings 4.2- 4.6 with 5 being the highest possible rating) on teacher surveys. In addition all Fellows completing surveys indicated that this experience will motivate them in the future to be an advocate for schools in their community, all stated that at the end of their Fellowship they had a better understanding of issues regarding K-12 education, and all said they would recommend participation in this program to upcoming engineering students.

Despite these similar positive impacts across all three Duke Engineering Teaching Fellows programs and the strong partnerships formed in all three programs, the same five issues were identified in all three programs as needing improvement:

- Fellows expressed a need for more in-depth training in concrete teaching skills, classroom management and developing and writing their own lesson plans;
- A format to provide uniformity and structure in lesson plans was needed;
- Teachers preferred that Fellows bring written lesson plans to class, which was difficult for new Fellows to accomplish at the beginning of the year;
- Fellows ranked teachers relatively low in providing adequate direction for planning and executing lesson plans;
- A systematic way to organize and disseminate lesson plans was needed and
- There was a need to have Teaching Fellows paired with their partnership teachers during their training to optimize their working relationship from the outset and establish a common way of conceptualizing and carrying out inquiry-based instruction.

Addressing these training and organizational needs, while building on the solid teaching partnerships already in place is one goal of the new, NSF funded Track 2 GK-12 Duke Engineering Teaching Fellows program, MUSIC (Math Understanding through Science Integrated with Curriculum) program. The following sections describe the more intensive, inquiry-based training program for Duke Engineering Teaching Fellows based on needs identified from these last five years of formative and summative program evaluations. A short definition of inquiry-based instruction and an overview of outcome studies of inquiry-based instruction applied to teaching K-12 science and engineering concepts will precede the description of the new Duke training program to provide rationale for selection of training in inquiry-based instruction as part of our training program.

What is Inquiry?

The following description of inquiry was created by Dr. Norman Budnitz, Research Associate with the TASC training initiative at Duke University, and is consistent with definitions of inquiry found in the National Science Educational Standards [1].

> *"Inquiry-Based teaching is the art of creating situations in which students take the role of scientists. In these situations, students take the initiative to observe and question phenomena; pose explanations of what they see; devise and conduct tests to support or contradict their theories; analyze data; draw conclusions from experimental data; design*

and build models; or any combination of these. These learning situations are open-ended in that they do not aim to achieve a single "right" answer. Nevertheless, students work under clear standards. They learn to observe keenly and thoroughly and to pose questions that are answerable, in part or in whole, through some meaningful test or exploration. They engage in trial and error, and they learn to analyze and reason carefully." [2]

Inquiry is a complex idea that means many things to many people in many contexts. It has been recognized in the development of the National Science Education Standards as an essential part of teaching K-12 science in this country.[3] Thus inquiry is more than just a scientific approach to investigating questions and enhancing knowledge process and content. It has far broader social implications by teaching and modeling cooperation and communication skills while solving problems, sharing and reflecting on new discoveries, and disseminating those discoveries broadly for the good of society. Inherent in the inquiry model is a non-competitive, respectful attitude towards the uniqueness of individuals and the wonder of the inquisitive minds of children. Inquiry is particularly well suited to fostering team building and team approaches to learning, both of which are gaining increased recognition as important skills to foster in undergraduate engineering curriculum nationwide.

Why Use Inquiry? Outcome studies related to inquiry and predicted impacts of Engineering Teaching Fellows utilizing inquiry-based instruction

Teaching science through inquiry has been shown to decrease achievement gaps among student subpopulations.[4,5,6,7,8,9] Other studies have shown that students report a more positive attitude towards academic subjects in which they excel.[10,11] Since inquiry-based instruction has also been shown to improve student and teacher attitudes toward science,[12,13,14] the following teacher and student impacts are anticipated for Teaching Fellows utilizing inquiry-based instruction methods:

- Improved interest and positive attitude in students towards math, science, and technology
- Improved interest and positive attitudes in teachers towards teaching math integrated with science and technology
- Improved math, science, and language arts end-of-grade test scores relative to scores of students of non-participating teachers
- Reduced gap between advantaged and disadvantaged students in math and language arts end-of-grade-test scores
- Decreased differences between advantaged and disadvantaged students in eligibility for 8th grade algebra
- Improved comprehension of knowledge-level science content and skill in scientific problem solving as measured by the statewide assessment in 2007.

New Duke Engineering Teaching Fellow Training Program

Beginning Fall 2004, the Duke Engineering GK-12 Teaching Fellows program revised its training protocol to include the following 5 formats: (1) Orientation meeting (2) Meeting in Physics Department for orientation to materials available for teaching engineering (3) Two full days of intensive inquiry-based instruction (4) One day of paired fellow-teacher training in

inquiry-based instruction and (5) Interdisciplinary Marine/Engineering Teaching Fellow training two-day workshop.

After a basic orientation to overall program structure, fellows attended a presentation by Dr. Bill McNairy in the Duke Physics Department to observe hands-on demonstrations of the equipment/engineering demos available to fellows on a check out basis for use in their lessons. Then, Engineering Teaching Fellows participated in two intensive days of hands-on training in inquiry-based instruction. This training focused on how to use inquiry-based investigations in elementary and middle school classrooms. To accomplish this, Teaching Fellows were introduced to several inquiry exercises (parachute construction, heat transfer, sound) in which they acted as students. The parachute construction activity was followed by a discussion of how this exercise exemplified an inquiry-learning experience: 1) Fellows in the role of "students" were provided with materials and simple instructions in order to accomplish an interesting task; 2) "students" made their own observations and asked their own questions; 3) "students" chose one of their own questions and devised a way to answer it; and 4) "students" communicated what they discovered to their peers. The first part of the activity was teacher-directed, in that "students" were required to accomplish a specific task following specific instructions, but then "students" took on the role of scientists, conducting their own inquiries and reporting their own, unique results.

These activities were followed by discussions entitled *What Makes a Good Teacher, Characteristics of Learning in Different Age Groups* and *Is It Inquiry?* Then, students used a worksheet of questions about lesson plans, entitled *How to Make a Good Lesson Plan,* to evaluate a heat transfer example lesson. Fellows were then given a written lesson and asked to analyze it using the *How to Make a Good Lesson Plan* list of questions.

During the 2nd day of the training, to help the Teaching Fellows further make the distinction between inquiry vs. non-inquiry based instruction, Fellows were asked to play the roles of elementary students as they conducted a simple inquiry activity. Working in small groups, Fellows conducted an inquiry activity on the nature of sound and were then given the same lesson written as a hands-on but non-inquiry activity. Fellows were then asked to compare and contrast the two sets of instructions. While both lessons contained elements of inquiry, the second was more teacher-directed and provided fewer choices and problem-solving opportunities for the students.

The final exercise of the training session was the creation of an outline for an inquiry lesson on a topic chosen from the NC K-8 science curriculum. The Teaching Fellows were asked to work in groups of two or three, and given a list of topics to choose from (e.g., states of matter for second grade, kinetic and potential energy for sixth grade, or friction for eighth grade). Each group was asked to devise inquiry activities that would allow students to explore these topics, using only materials that could be commonly found in classrooms or were otherwise inexpensive and easily obtained. The groups were also reminded to use the lists of questions presented earlier (*How To Make a Good Lesson Plan* and *Is It Inquiry?*) as they outlined their lessons. After the groups came up with their plans, they presented them to each other in order to obtain feedback and additional ideas.

Fellows subsequently attended a Paired Fellow/Teacher Training Workshop with their partner teacher. Fellows and teachers were guided through inquiry-based investigations in the role of "students" and then guided in developing the first jointly constructed lesson plan for use in their actual placement classroom.

Intensive Inquiry-Based Training Outcomes

Post surveys were given to fellows and teachers attending all inquiry-based training workshops described above. Results of the 2-day intensive inquiry-based training with fellows only are reported below. Post-training surveys indicate that teaching fellows comprehended important applications of inquiry-based teaching techniques based on only 2 days of intensive training. When asked on a post training survey "*As teaching Fellows*, *what would you do differently than before the training?"* Fellow's answers include:

- "really make an effort to not preach, preaching is to say: this is why something happens, take my word for it, inquiry says here is something observable, now test it"
- "put more emphasis on experiments"
- "before training, I might have already drawn up a data table for students that left no design for them"
- "get the students to ask more questions and ask students more questions rather than lecture-style teaching"
- "more exploratory activities and less lecture style"

Fellow survey responses to "*What skills did you gain from your experiences in the workshop?"* further indicate Fellows' new comprehension of important facets of inquiry-based instruction:

- "the importance of reflection, you can't make a great lesson plan on intuition, it has to meet certain criteria and takes planning"
- "how to get students to expand their thought processes"
- "learning the importance of asking open-ended questions to students"

When asked "*In your own words, what is inquiry-based teaching*", Fellows responses again indicate a good beginning understanding of inquiry:

- "Inquiry is prompting the students to ask questions, questions of the material, and questions of themselves"
- "teaching through student exploration and examination"
- "allowing a student to ask questions about subject matter and then posing a challenge for them to investigate and answer their own question using scientific methods"
- "having students learn and discover on their own, having them come up with questions and discover their own answers"
- "where students discover and devise their own way of experimenting and understanding a certain concept"
- "letting students discover on their own versus showing and telling them"
- "teaching that inspires and involves questions to and from the kids in class"
- "having kids come up with questions and observations about why something works the way it does without directly telling them the answer"
- "letting kids learn by coming to the conclusions using their own methods"
- "guiding the students to help them learn things on their own through their own creativity and curiosity"

- "inspiring kids to learn for themselves, letting them explore and do the science by just guiding them and not telling them exactly what to do"

Overall, post training fellow surveys were consistently positive in endorsing the value of the new training program. When asked "*What were the most beneficial parts of the workshop*?" fellows overwhelmingly endorsed participation in the hands-on activities where they were placed in the role of "students", allowed to practice inquiry activities, given lots of good examples of inquiry, and actually allowed to formulate inquiry-based lesson plans and hear lesson plans of other Fellows. These results from fellow post training surveys underscore the importance in an Engineering Teaching Fellows training program of placing fellows in the role of "students" and allowing them to experience hands-on inquiry-based activities as well as grapple with designing their own lesson plans in a group setting where they can brainstorm and receive feedback from other teaching fellows as well as from instructors experienced in teaching K-12 students in inquiry-based methods.

Ongoing Training, Lesson Plan Dissemination Plan and Mid-Year Fellow Surveys

In addition, all Duke Engineering Teaching Fellows participate in 13 bi-weekly ongoing 1 to 1.5 hour instruction/supervision sessions with the Program Coordinator and a TASC trainer to reinforce initial training, provide instruction in classroom management, and continue developing inquiry-based lesson plans tailored to fellows' classroom placements. Fellows are provided a structured format for writing their lesson plans, which are reviewed by the MUSIC Program Coordinator and a TASC trainer and will be published on TeachEngineering.com, the NSF funded national science digital library to provide national dissemination of their work (www.teachengineering.com). With the new training revisions in effect, fellows were able to produce higher quality, more comprehensive inquiry-based lesson plans much earlier this academic year (within one month of classroom placement). Mid-year fellow surveys also reinforced the value of the hands-on demonstrations early in fellows' training as well as the high priority fellows placed on continuing to share and brainstorm lesson plans with other fellows afforded by the supervised structure of the bi-weekly training meetings, suggesting the importance of ongoing, year-long training.

Summary

Inquiry-based instruction has been found to be an important instructional modality for successful teaching of technology, science and math integrated into all areas of curriculum since demonstrated impacts include reductions in gaps between advantaged and disadvantaged students in math and language arts, improved math and language arts end-of-grade test scores relative to scores of students of non-participating teachers, decreased differences between advantaged and disadvantaged students in choices of challenging science and math courses, especially 8th grade algebra, and improved comprehension of knowledge-level science content and skill in scientific problem solving. Due to these demonstrated impacts of inquiry-based instruction and training needs identified over the last 5 years of the Duke Engineering Teaching Fellows Programs, intensive instruction in inquiry-based instruction methods has been incorporated into the evolving training program for Duke K-12 Engineering Teaching Fellows. Results of formative assessment of this new inquiry-based training model indicate the

importance in such a training program of placing teaching fellows in the role of "students" and allowing them to experience hands-on inquiry-based activities as well as grapple with designing their own lesson plans in a peer group setting where they can brainstorm and receive feedback. Furthermore, using such a hands-on and intensive training modality resulted in clear evidence that fellows absorbed and were able to articulate important components of inquiry-based instruction after only 2 days of instruction. Nevertheless, mid-year fellow surveys also indicated the importance of ongoing, year long, bi-weekly structured training meetings to allow fellows to brainstorm and share successful lesson plans as well as participate in additional demonstrations of inquiry-based activities across a variety of content areas. Next year's bi-weekly fellow meetings will increase the number of hands-on demonstrations of different lesson plan activities and time allotted for brainstorming lesson plans among fellows based on mid-year survey requests from this year's teaching fellows.

The creative lesson plans of these Engineering Teaching Fellows are published on TeachEngineering.com, a National Science Digital Library. End of year program evaluations will continue for the 2005-2008 school years and will further assess impacts on students taught by Duke Engineering Teaching Fellows as well as additional outcomes of this state-of-the art training program.

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