AC 2007-1754: THE DEVELOPMENT, IMPLEMENTATION AND ASSESSMENT OF AN ENGINEERING RESEARCH EXPERIENCE FOR PHYSICS TEACHERS

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The Development, Implementation and Assessment of an Engineering Research Experience for Physics Teachers

Abstract

The Summer Teacher Experience in Packaging- Utilizing Physics (STEP-UP) program at the Georgia Institute of Technology provides a comprehensive research experience for up to ten high school physics teachers per summer. Its objective is to train metro Atlanta high school physics teachers in both modern physics concepts and their applications to engineering as well as their relevance to today's technology. The program runs successfully through collaboration with the School of Electrical and Computer Engineering, microelectronics Packaging Research Center (PRC) (an NSF Engineering Research Center) and the School of Physics. The program has three components: (1) to enables teachers to fully take advantage of their subsequent research experience, a two -week course on modern physics, with a laboratory component is given; (2) a three day module course on applications of modern physics concepts to microelectronics; and (3) a five and a half week summer research experience. Workshops are also held during the teachers stay at Georgia Tech to help them with the development of lesson plans and classroom material derived from their research experience.

Currently in its third year, the program has had 25 participants. Participating teachers have commented on how they have gained confidence in teaching physics and connecting physics to engineering applications and thus have been able to better instill an interest in engineering careers in their students. In order to assess the program's outcomes, a mixed method approach was used that involved both quantitative and qualitative evaluations. From the assessment results and suggestions offered, new program facets have been added each year. This paper discusses in detail the structure and implementation of the program, and how it impacts the teachers and their students.

Introduction

A major national educational problem is the lack of interest and low enrollment in science classes, particularly physics, among high school students. There is a vast amount of statistical data on the scope of this problem[1,2] indicating two root problems that must be corrected. First, only a fraction of the nation's physics teachers (~33%) have a degree in physics or physics education[3]. Other sharp contrasts emerge along geographical lines and racial composition of high schools. In the south, only 24% of physics teachers have a degree in their field[4]. Contrasting this statistic with the well known result that a thorough knowledge of course material taught in high school physics is essential to good teaching in math and science[5,6] underlines a disturbing situation in high school science education in the south. The second problem faced by science education is the ability to motivate students' interest in these fields. To do this, the relevance of the course material to every day life must be demonstrated. This cannot happen if teachers are unfamiliar with basic concepts in physics, let alone modern applications derived from these principles. It is extremely difficult to encourage curiosity or give a clear understanding of science concepts to students when the teachers themselves are not familiar with basic principles. It is therefore not surprising that physics enrollment is a national problem. This situation is extremely distressing since science and technology are critical to protecting our nation's economic growth, the vitality of our industries, and the productive use of resources.

In this paper we focus on the situation of high school physics education in metro Atlanta. Within this district, discussions with high school teachers, administrators, and students, show three reasons emerging that begin to explain the low physics enrollment in public schools. First, as already stated, a majority of high school teachers lack degrees in physics. As a result, very few physics teachers feel confident enough to cover modern physics subjects in their classes. Second, given the current limited state of public school funding, high school science teachers simply do not have sufficient resources for demonstration tools. Because visualization is key to understanding and modern physics so buried in the inaccessible subatomic world, the inability to get these tools is doubly crippling to teaching modern physics concepts. Finally, minority students in Atlanta's public schools are unlikely to see physical sciences as a career option. These students cannot visualize how science and technology affect their every day life or the future benefits they can derive by being literate in science. Most engineering fields, especially electrical and mechanical, are based on modern physics, and one cannot expect students without exposure to these materials to choose engineering as a career.

In this paper we describe an attempt to correct some of these hindrances to high school science education in metro Atlanta. A collaboration between the Schools of Electrical and Computer Engineering and Physics has led to a research experience, backed by a modern physics tutorial, for metro Atlanta physics teachers. The program is called Summer Teacher Experience in Packaging – Utilizing Physics (STEP-UP) and has been funded by the National Science Foundation (NSF) since 2004 as a Research Experience for Teachers (RET) site. To date, 25 teachers from 25 different high schools spanning 6 metro Atlanta school systems participated in the program. The only criteria used to pick teachers for the program is that they teach physics full time and come from as many different schools as possible. Using these restrictions the teachers enter the program with on average 7 years of teaching experience. Their educational background varies considerably: only ten of them have BS degrees in physics with the rest spread over degrees in chemistry (2), biology (1), philosophy (1), MSE (1), EE (1), ME (3) and science education (6). Among the 25 participants, 36% of them were female and 32% African Americans. The teachers received a stipend of $5,700 for participating in the 8 week summer program and $1,000 of lab supplies and materials to help design and develop effective lesson plans and courseware to be used during the school year. As we will show below, teachers had an eye-opening experience and left the program with refined knowledge in modern physics and an increased awareness and enthusiasm for their ability to describe what an engineering career entails. An important indicator of the success of the program is its impact on the desire of the teachers to further pursue science and engineering education.

Program Description

The program is intended to enhance the knowledge of Atlanta physics teachers in modern physics topics and show how these principles are applied in engineering applications. This is accomplished through a multi-disciplinary research experience in microsystems packaging combined with an intensive course in modern physics. The specific goals of the STEP-UP program are to: (1) enhance and update the knowledge of participating teachers in modern physics; (2) provide examples of engineering applications of fundamental physics concepts; (3) familiarize participants with engineering research tools and techniques; (4) provide a research experience in fundamental and prototype microelectronics packaging consisting of a multi-disciplinary environment with an industry perspective; and (5) provide and improve their understanding of engineering careers.

The program is broken into four parts: (1) an intense two-week course on modern physics (with a laboratory component to reinforce classroom concepts) that will enable participants to fully take advantage of their subsequent research experience; (2) a two day module on applications of modern physics concepts in microelectronics packaging; (3) a five and a half week summer research experience; and (4) a series of workshops and industry field trips to develop classroom lesson plans that incorporate their research experience and discuss engineering careers.

The two-week modern physics course and laboratory covers wave-mechanics, basic quantum principles, and their relationship to solid state physics. A detailed course syllabus is provided in Table 1. Used as a bridge to the teachers' research experience, the course develops ideas of band-structure, basic pn-junctions, and logic gates. This course includes both class lectures and labs on modern physics. The course enhances the teachers' knowledge of modern physics topics and provides them engineering and technology applications of these concepts. Coupled with the lectures is an additional 20 hours, five 4-hour, labs. The labs are intended to both stress lecture topics as well as beginning hands-on experience using modern laboratory equipment (see Table 1 for lab topics). The teachers receive 60 hours of modern physics instruction that they can use towards Staff Development Units in their school systems.

Table 1. Modern physics course syllabus

	Monday	Tuesday	Wed.	Thursday	Friday
Week 1 Course Topics	• Orientation	• Interference	• Basic Thermo	• Particles & Waves	• Bohr Atom
	• Course Intro	• Diffraction	• Ideal Gas	• Blackbody & Emission Spectra	• Particle in a Box
	• Wave Basics	• Confined Modes& Quantization	• Heat Conduction	• Photoelectric Effect	• Spin & Angular Momentum
Week 1 Labs			Lab		Lab
			Atomic Spectra		Wave-Particle Duality
			Micro Waves		Hall Effect
Week 2 Course Topics	• Quantum Oscillators	• Auger Electrons	• Pauli Exclusion	• Band Structure	• pn Junction
	• Phonons & Photons	• Tunneling	• FreeElectron Model	• Semi-conductors	• Transistors
	• Lasers	• Tunneling Microscope	• Electrical Conduction	• Doped Semiconductors	• Optical Properties
		• Photoemission			
Week 2 Labs	Lab		Lab		Lab
	Photo-electric effect		Solid Temp-erature Effects		Transistors

	Frank-Hertz		**PN Junctions**		

Once the modern physics introduction is completed, the teachers take a two-day module on microelectronics packaging fundamentals. This module connects the physics course with their engineering research experience. It provides the teachers with an overview of microelectronics packaging issues and technologies and prepares them for their research experience. Most importantly, by covering subjects from electrical design, materials, substrate fabrication to assembly, thermal management and testing, this module provides the teachers a system-level view of microelectronics packaging.

Before starting the research experience component, teachers spend half a day learning basic lab safety rules. Only then they are admitted into the labs, where they are trained in techniques, tools and special equipment they'll use for their summer research. Each teacher works closely with a faculty member and a graduate student on an interdisciplinary research project. Detailed descriptions of research projects conducted by the STEP-UP teachers last summer (typical of those from previous years) are given below. On the last day of the program the participants present their research projects orally to an audience of faculty and graduate student mentors, and school system science coordinators.

Determination of pre/post process surface roughness and comparison with copper film adhesion on multiple polymer substrates: Development of System-On-Package (SOP) technology depends on the use of thin film layers that serve the functions of multiple components embedded in a single chip. Adhesion between layers depends on a mixture of mechanical and chemical mechanisms. This project analyzed the roughening process to determine its effect on micro-roughness (~100 Å) and macro-roughness (>1000 Å) of a dielectric polymer. Those roughness values were then compared to peel test data to determine which type of roughness correlated best with peel strength. It was found that the Permanganate etching process created a larger difference in the macro-roughness of a material. It was also determined that while peel strength increased as both types of roughness increased, there was a more noticeable correlation between peel strength and macro-roughness than micro-roughness.

Synthesis and Characterization of Graphene: Graphene is a planar sheet of sp^2 bonded carbon atoms. Recent work has demonstrated coherent and ballistic transport (resistance independent of length) of electrons in these sheets at room temperatures. Furthermore, the recent discovery that single graphene sheets can be used to make electronic gates all point to a new direction for two-dimensional electronics. However, before this material can be successfully utilized in the development of better electronic components such as field effect transistors (FET), it is necessary to understand how to make graphene layers of predictable thickness, control the long range order of the sheets and know how they interact with the substrate on which they grow. The best method to produce graphene is by annealing SiC samples using various heating regimes. Graphene forms at the surface of SiC when it is heated above ~1150C. Above this temperature silicon sublimates from the surface leaving behind atomically thin layers of carbon that crystallize into graphene sheets.

Graphite –new foundation for microelectronic circuitry: While carbon nanotubes (graphene sheets wrapped into a tube) have been used as Field Effect Transistors (FET), the inability to arrange millions of tubes for large scale integrated electronics limits their uses in modern chips.

However, the special electronic properties of nanotubes comes, not from their shape, but because of their cyclic boundary conditions. This implies that by cutting ribbons of graphene sheets into different widths or shapes will allow them to be used as FETs. It has now been shown that band gaps of graphene ribbons can be controlled by adjusting their widths. Also, whether or not a ribbon is conducting or metallic is controlled by the cut direction. This means that both wires and pn junctions can be made from a single sheet without any interconnects and that standard lithographic techniques can be used to make large integrated circuits from these sheets.

Fuel Cell Vent Membranes: A Study in CO_2/Methanol Selectivity: Highly selective polymer membranes may be a viable option for venting carbon dioxide from the anode side of direct methanol fuel cells. To be effective they must let out the carbon dioxide but keep the methanol in. Poly(dimethyl siloxane), PDMS, has been widely shown to be highly permeable to carbon dioxide but no data has been published about its methanol permeability. This paper describes PDMS's carbon dioxide to methanol selectivity as well as the effect of adding 1,6 Divinylperfluorohexane or 1,9 Decadiene at the time of polermization in an attempt to improve selectivity.

Silole Derivative Properties in Organic Light Emitting Diodes: Organic light emitting diodes, abbreviated as OLED, were fabricated using a new family of materials based on silole derivatives. Siloles are a family of materials that have been found to have high external quantum efficiencies and electron transport properties. OLEDs are much sought after in the scientific community because they are very thin multilayer devices that do not require a backlight and provide brighter, crisper displays on electronic devices. These devices are furthermore beneficial because they are printed on plastic making displays flexible and lightweight. OLEDs are efficient, using less power than conventional LEDs or liquid crystal displays (LCDs). And, due to all of these benefits, OLEDs are much less costly to fabricate than traditional LCD displays.

Recording Volume Holograms in Photopolymers for Optical Interconnection: Chip-to-chip optical interconnects are essential for new generations of systems requiring high data transfer rates. Both waveguide-based and free-space interconnections using holograms recorded in thin photopolymer films are being investigated. Depending on the interconnection strategy, holograms are recorded using two plane-wave (for waveguide-based interconnection) or two spherical beams (for free-space optical interconnection). Since the hologram's strength depends on exposure time, material characterization is performed to obtain the optimum exposures.

Application of Polymers for Optical Data Transfer: One method to construct optical data transfer pathways to connect circuit boards is to construct the pathways from polymers. The polymers can be made into optical wave guides so digital information can be transmitted by small lasers embedded into the circuits in computer applications to replace copper connections. Optical wave guides use the principle of total internal reflection to provide a pathway for the light from the laser. The materials used have different indexes of refraction, so the light travels through the wave guide. The laser light takes the digital information and converts it into an optical signal, which is received by a detector on the other end of the wave guide where it is converted from the optical signal back to a digital signal that can be used by the computer processor.

Multilayered Finite Difference Method for Characterization of Power /Ground Planes: Multilayered packages and boards such as high performance server boards contain thousands of signal, lines, which have to be routed on and through several layers with power/ground planes in between. There can be noise coupling not only in the transversal direction through thru power/ground planes in such a structure, but also vertically from one plane pair to another through the apertures and via holes. In addition, the continuous increase in power demand along with reduced V_{dd} values results in significant current requirement for the future chips. Hence, the parasitic effects of the power distribution system become increasingly more critical regarding the signal integrity and electromagnetic interference properties of cost-effective high-performance designs. A multilayer finite-difference method (M-FDM),which is capable of characterizing such noise mechanisms provides a simple and efficient method for the modeling of multilayered structures without any limit on the number of layers.

Polymers for Electronic Packaging: The integration of capacitors is of great importance for electronic systems. Modern microelectronics requires capacitors with higher capacitance and shorter distances from devices. Integral or embedded capacitors are a promising technology that could significantly reduce size, weight, and cost of electronic products, while improving performance, reliability and design options. Developing organic substrate compatible high dielectric constant (K) material is the major challenge for capacitor technology. Polymer composites with ceramic nano-fillers are the only candidate systems. However, to achieve a high K, a high ceramic filler loading has to be used, creating dispersion problems in the polymer matrix. Thus, novel fillers are being pursued to form the composites and to investigate their effects on electrical performance.

Two industry field trips are organized to enhance teachers' research experiences. One trip is to Georgia Power's Plant McDonough and the other is either to Siemens or Lockheed Martin. These filed trips provide opportunity for teachers to get familiar with each industry, interact with engineers, and learn more about engineering careers.

Each teacher prepares an electronic portfolio before the end of the program. Electronic portfolios are kept at the program web site and consist of the following:

- Modern physics course: content, engineering applications, and lab investigations
- Description of tools, techniques, and special equipment utilized in teacher's microelectronics research
- Research report inclusive of research techniques, tools, data, discussion and conclusion associated with the research project
- Design of a lesson plan or unit (inclusive of assessment strategies) derived from the research experience
- Engineering career information and the educational preparation necessary to pursue them

The portfolios help the teachers reflect on and organize their summer experience. These portfolios can be accessed by any of the teachers and therefore act as a shared resource once they are back in their school districts. All the teachers have used the portfolio as data bases for the results from their modern physics labs as well. They then use this data at their schools as a substitution for the actual experiments that they lack.

Four half-day workshops are held during the summer at Georgia Tech to develop inquiry based lesson plans and classroom material encompassing the teachers' research experience. In addition to these, two additional half-day workshops are held during the school year, one in October and the other in April. These two workshops create a forum to interact and share teaching experiences among all teachers (past and present) who participated in the program. It also provides the program staff an opportunity to implement some of the planned assessment tasks.

Workshop 1 (week 3): National Science Education Standards and the Georgia State Quality Core Curriculum (QCC)[7-10]. Instructed by Dr. George Stickel (Science Coordinator, Cobb County School District).

Workshop 2 (week 3): Overview and application of "best practice" research for improving student achievement and the use of science inquiry in developing hands-on physics lesson plans. Instructed by Michael Downing (Physics teacher, Fernbank Science Center).

Workshop 3 (week 5): Part 1: Development and contents of lesson plans and engineering careers. Instructed by the authors. Every teacher received a copy of the "Engineering Careers" video to share with his/her students. Part 2: College admission process instructed by Georgia Tech Admissions Office.

Workshop 4 (week 7): Evaluation of progress by teacher participants and final formatting lessons for classroom use and for dissemination.

Workshop 5 (Fall): Examples of inquiry teaching, academic year activities and gender equity.

Workshop 6 (Spring): Examples of lesson plans developed by the teachers and their implementation.

The participants of the program continue to interact with the authors during the school year beyond the program. The teachers and their students visit Georgia Tech where they spend a full day on campus. In the morning they attend a special admission session and then take an instructed campus tour. In the afternoon the groups tour the modern physics and ECE research laboratories.

Participant Recruitment and Selection

Participants for the STEP-UP program are recruited from metro Atlanta school systems. Program information and application packages are sent to each school system's science coordinator as well as science department heads and principals at all high schools in the system. Program information and application material is also available at the program website. Participation in the program is only open to in-service high school physics teachers who teach physics courses regularly in one of these school systems. During the lifetime of the program only one teacher per high school is accepted to the program. Once accepted, teachers' files are copied and given to the potential research mentors. Research mentors, after reviewing the files, submit the three top choices to the program directors who then make the final matches.

Program Assessment

The assessment model has two primary objectives: to assure that the enhancement course and research experience components are as educationally effective as possible and that the summer experience is transferred into the classroom during the academic year. A mixed method employing both quantitative and qualitative data analysis is used to conduct the assessment. Since the program has several components, the assessment methods used to review each component varies appropriately. As summarized in Table 2, the assessment plan includes the evaluation of the individual components of the program, the overall impact of the program on the participants' knowledge and skills, and the effectiveness of the transfer of the summer experience to the classroom.

Table 2. Assessment goals and instruments

Assessment Goals	Program Components	Assessment Methods
Effectiveness of the individual components of the 8 week summer experience	Modern physics course	Pre-Test/Post-Test, focus group, end-of-course survey
	Research experience	Teacher feedback survey, mentor feedback survey, research paper, research presentation
	Workshops	Focus group, teacher feedback survey
Quality of individual components as each relates to overall program objectives	All program components	Pre- and post-program surveys, exit survey
Determination of the utilization of the summer experience and transfer to classroom	High school environment activities and programs	Teacher utilization survey, lesson plans, class room observations
	Long term student impact	Georgia Tech admissions data

In this paper the assessment results from the past three program years are included except the evaluation of academic year activities of the third year which will be conducted during spring semester of academic year 2006-2007. All the data findings presented in the next section are averaged over three years unless stated otherwise. The total number of teacher participants over the three year period is 25, however the number of responses may vary depending on missing data and response rates.

Results and Conclusions

According to the pre-program questionnaire administered on the first day of the program, the teachers reported that they were not confident or only slightly confident in three areas: expertise in modern physics concepts, advisement of students about physics programs and careers in physics (Table 3).

Table 3. Pre-program survey

N varies due to missing data on individual questions	**Extremely confident**	**Moderately confident**	**Slightly confident**	**Not confident**	**Do not know**
Possess expertise in modern physics concepts	3	4	10	8	0
Use inquiry-based instructional method	6	13	6	0	0
Pace instruction to cover material	5	14	4	1	0
Lead class discussion on text material	13	10	1	0	1
Answer subject-based student questions	14	10	1	0	0
Design physics tests	9	13	3	0	0
Select physics text books	8	10	1	2	2
Supervise student physics projects	7	10	5	1	2
Advise students about physics programs	6	7	10	1	1
Advise students about careers in physics	5	5	13	2	0

Evaluation of Individual Components

Data from assessment instruments demonstrate the effectiveness of the program and the extent teachers transferred the newly acquired knowledge and skills to their students during the school year. Three assessment methods were used to address the effectiveness of the two-week modern physics course. First, a pre-test/post-test design was used that tested participants in four substantive topic areas covered in the course. Second, a focus group was held at the midpoint of the two-week course to review the extent to which the instructional needs and program expectations were being met (feedback provided to instructor to make adjustments as appropriate). Finally, a post physics course evaluation was administered.

The pre-test and post-test measured knowledge and skills in waves, modern physics, condensed matter and technology topic areas. The data presented in Table 4 is average performance over the three program years by topic and total.

- Teacher scores increased most on the “condensed matter” topic where the overall gain was 47.6%.
- For the other three topics, correct answer percentage gain ranges from 22.2% to 27.9%.
- Total percentage gain for all questions was 32.8%.
- The highest gains were observed in the topic areas with the lowest pretest performance.

Table 4. Pre- & post-test results

N=25	Total Correct Scores		Percentage Correct by Course Topic			
	#	%	Waves	Modern Physics	Condensed Matter	Technology
Pre-test	40.50	23.5%	33.5%	41.7%	10.7%	18.4%
Post-test	92.88	56.3%	61.4%	63.9%	58.3%	44.4%
Change	**+52.38**	**+32.8%**	**+27.9%**	**+22.2%**	**+47.6%**	**+26.0%**

The findings from the focus groups conduced at the course mid-point confirm the relevance of the course material to elevate the level of knowledge of high school physics teachers. Highlights from the focus group on modern physics course are provided below:

- Teachers expressed enthusiasm about the college level instruction and recognized the importance of college-level instruction even if material is not directly applicable to the high school classroom.
- Most teachers expressed the desire to put course material in context that relates to the high school environment.
- Since teachers had varying degrees of physics background, some had difficulty understanding the more complex material.
- All agreed that the course was a positive experience, and thought the college environment and level of material were beneficial.

The end-of-course evaluation shows that the course was beneficial to all teachers (Table 5). Responses to a set of questions about various ways to participate in the course and use course material show a positive pattern. Most of the teachers tended to ask questions, read additional materials and access internet sites related to course content. In addition, even with the varying levels of physics knowledge before the course, teachers reported increased confidence to perform physics related tasks. As a result of the course, confidence among teachers increased dramatically for expertise in modern physics concepts, ability to pace instruction to cover material, lead class discussion on text material, answer subject-based student questions, advise students about physics programs and careers in physics and engineering. All 25 participants were "very satisfied" with the knowledge and preparedness of the course instructor.

Table 5. End of course questionnaire

Extent to which the Modern Physics course had an impact on confidence in each of the following areas as it relates to high school physics (N=25)	**Greatly increased confidence**	**Moderately increased confidence**	**Minimally increased confidence**	**No impact**
Possess expertise in modern physics concepts useful for teaching	12	11	2	0
Use of inquiry-based instructional method	2	11	6	6
Ability to pace instruction to cover material	3	10	7	5

Lead class discussion on text material	8	13	4	0
Answer subject-based student questions	11	12	2	0
Design physics tests	1	8	7	9
Select physics text books	4	7	6	8
Supervise student physics projects	2	9	10	4
Advise students about physics programs of study	11	10	1	1
Advise students about careers in physics and engineering	13	10	1	1

The content and quality of the research conducted is evaluated by the research report and oral presentation. Other aspects of the research experience are assessed by two surveys. One is administered to teacher participants and the other to the mentors. Summative results of the teacher survey from the past 3 years are provided below, in Tables 6 and 7. Findings from the 2006 mentor survey are presented in Table 8.

Table 6. Involvement in activities related to the research experience

Frequency teachers did each of the following activities as part of the research/lab experience with the mentor (N varies due to missing data on individual questions)	**Regularly**	**Sporadically**	**Once or twice**	**Not at all**
Attend lab/staff meetings	9	6	4	6
Attend brainstorming sessions	6	4	2	12
Work with other Georgia Tech students	13	6	2	4
Review material needed for lab work	13	5	5	2
Assess progress on research assignment	12	4	4	4

Table 7. Research experience participant survey

	Great extent	**Moderate extent**	**Small extent**	**Not at all**
To what extent was your mentor prepared for your research experience?	11	8	0	4
To what extent did your mentor understand the purpose of your STEP-UP program?	10	8	4	2
To what extent did you engage in research tasks that you can adapt to your classroom?	9	5	7	3
To what extent did your mentor develop clear research objectives for your experience?	14	5	3	3
To what extent did you understand your research assignment?	18	4	2	1
To what extent was your assignment appropriate to you level of understanding?	15	6	0	3
To what extent did you interact with your	10	7	7	1

mentor?				
To what extent did you feel welcome in the lab by your mentor?	20	2	2	1
To what extent did you interact with a graduate student assigned to you?	16	2	4	3
To what extent did the research experience enhance your understanding of applied research?	19	2	3	1

A mentor survey was developed and administered the first time in summer 2006. Five out of nine mentors responded to the questionnaire (Table 8). Responses were very favorable in terms of both the quality of the STEP-UP participants and the overall program structure. STEP-UP teachers were viewed as willing and motivated to work in the labs. Mentors strongly agreed the program is valuable for high school teachers and their experience as mentors were meaningful. In addition to the data in Table 8, all five mentors reported that they were satisfied with the procedures used to match teachers and mentors had no additional suggestions or recommendations to improve upon those procedures.

Table 8. Mentor survey

N=5	**Strongly agree**	**Agree**	**Disagree**	**Strongly disagree**
Participating in this program was worth my time	1	4	--	--
This program was valuable to others in my lab	1	4	--	--
I believe STEP-UP is valuable for high school teachers	4	1	--	--
Participating as a mentor is meaningful to me	4	1	--	--

Workshops are organized to identify and discuss strategies to deal with common challenges high school physics teachers face regularly. After the fourth workshop a teacher survey is administered to measure the effectiveness of the workshops (Table 9). While the first workshop on standards and outcomes was not viewed as highly useful, the second workshop on teaching physics was rated extremely/very useful by majority of the teachers. Similarly, over 85% of teachers who attended the workshop facilitated by the STEP-UP Director rated the third workshop extremely helpful. In contrast to the previous years, the fourth workshop run by the teachers during the summer 2006 was not viewed as successfully as the previous two years. Overall, the workshops were rated most helpful for teaching applied physics concepts and implementing hands-on physics projects.

Table 9. Evaluation of workshops

Helpfulness of the workshops to address each of the following challenges faced by high school physics teachers (N varies due to missing data on individual questions)	**Extremely helpful**	**Somewhat helpful**	**Minimally helpful**	**Not helpful**	**Not applicable**
Leading stimulating class discussions on physics topics	8	4	9	2	2
Using inquiry-based learning	3	6	11	4	1

techniques to teach physics					
Strategies to teach critical thinking skills	2	8	11	3	0
Teaching applied physics concepts	7	9	6	2	1
Adopting innovative methods to teach applied physics	6	7	4	7	1
Implementing hands-on physics projects	6	9	7	2	0
Using teaching methods to stimulate student interest in physics	6	7	8	4	0
Adapting the STEP-UP research experience to the classroom	6	7	9	3	0
Adapting inquiry-based learning to the high school environment	2	8	12	3	0
Adapting applied physics lessons to fit within the state curriculum standards	3	6	12	4	0

Program Effectiveness

After the final summer workshop, an electronic exit survey is distributed (Table 10). The findings from this survey indicate an overwhelming sense of renewed enthusiasm for teaching and desire to learn more about physics. When asked about the effectiveness of the program to meet eleven professional goals, teachers reported extremely or moderately effective for nine of the goals. Other highlights that pertain to program effectiveness include:

- Majority of teachers said they were planning to share what they learned with other teachers.
- Majority of teachers said the program stimulated them to encourage students to major in science/technology fields.
- Majority of teachers said the program increased their ability to teach the relationship between physics and microelectronics.
- Majority reported increased confidence as physic teachers and the commitment to being effective teachers.
- Most teachers are likely to organize field trips.

Table 10. Post-program survey

Effectiveness of the STEP-UP program to achieve each of the following professional goals (N varies due to missing data on individual questions)	**Extremely effective**	**Moderately effective**	**Slightly effective**	**Not effective**
Increased my expertise in modern physics concepts	15	8	2	0
Increased my ability to use inquiry-based instructional methods	3	6	11	4

Enhanced my enthusiasm for teaching high school physics	8	13	1	3
Stimulated my commitment to being an effective teacher	11	9	2	3
Increased my confidence as a physics teacher	11	5	6	3
Enhanced my ability to teach the applications of physics	8	13	4	0
Increased my ability to teach relationships between physics & microelectronics	13	9	3	0
Increased my expertise needed to offer lab-based instruction for my students	6	8	9	2
Stimulated my interest to organize student field trips to Georgia Tech	13	7	2	3
Stimulated my dedication to encourage students to major in science/technology	12	10	3	0
Stimulated me to share what I learned with other teachers	13	8	3	1

Since the transfer of the STEP-UP experience to the high school classroom is a principle goal of the program, advisement of students is an indicator of the application of increased knowledge, expertise and confidence as a physics teacher. A more direct comparison of the pre- and post-program data is given below in Table 11. At the end of the program, almost all the teachers reported an increase of expertise in modern physics concepts. Similarly, a majority of the teachers said the program was effective to stimulate them to encourage students to major in science/engineering. On the other hand, less than half of the teachers (9 of 24) said that the workshops increased their ability to use inquiry based instructional methods. While this may suggest that the program did not adequately instruct teachers in inquiry-based methods, other survey findings provide additional insight. Inquiry-based teaching in the high school classroom is a timely topic in secondary education and is the focus of numerous training programs offered by the public school systems. Thus, efforts in the STEP-UP program to increase knowledge in this area may not have had the impact that was reported about other STEP-UP modules if teachers had already attended training in these methods. This is the case with the majority of the teachers who reported in the pre-program survey that they had already attended several such workshops and they felt very confident to integrate inquiry based instruction in their teaching approach. (see Table 3). Hence the workshop given during the summer in this area did not contribute as much to increasing knowledge and confidence in inquiry-based instructional methods.

Table 11. Comparison of pre- and post-program results

2005-6 Pre-Program Survey	**Extremely/ Moderately confident**	**Slightly/ Not confident**	**2005-6 Post-Program Exit Survey**	**Extremely/ Moderately effective**	**Slightly/ Not effective**
Possess expertise in modern physics concepts	7	18	Increased my expertise in modern physics	23	2

			concepts		
Use inquiry-based instructional methods	19	6	Increased ability to use inquiry-based methods N=24	9	15
Advise students about physics programs of study	13	12	Stimulated dedication to encourage students to major in science or engineering	22	3
Advise students about careers in physics	10	15			

Transfer of Experience into Classroom

The following list identifies the strategies that may be used by teachers to transfer to their high school classrooms the knowledge and skills gained as STEP-UP participants are,

- Using the lesson plans developed during the summer
- Developing and implementing hands-on teaching methods
- Presenting their summer research project to their students
- Establishing engineering clubs and/or becoming advisor to such clubs
- Inviting Georgia Tech ECE students as speakers to their classrooms
- Showing the "Engineering Careers" video to their classes and advising their students in engineering and science college programs
- Organizing high school student visits to Georgia Tech

The above activities are evaluated over time in order to capture the full impact of the experience. Four approaches to "transfer of experience assessment" are identified below:

1. Conduct surveys at the follow-up fall and spring workshops that focus (a) directly on specific activities, both planned and completed, that indicate utilization of STEP-UP experience in the high school and (b) devote some time to group discussion of special initiatives to transfer summer experience to the classrooms.
2. Facilitate and track efforts by teachers to utilize resources available through Georgia Tech to enhance physics education for their students.
3. Visit participant schools to observe teacher instruction while putting into action material obtained during the summer experience.
4. Maintain dialogues with selected teachers who prove particularly successful at adaptation of the summer program experience and skills to the high school environment.

In order to track the specific activities that are undertaken during the school year a "utilization questionnaire" has been developed and administered to the first two cohorts of the STEP-UP participants. The responses are provided the following two tables, Table 12 and Table 13.

Table 12. Utilization survey-I

2004 & 2005 cohorts (N=13)	**The year before STEP-UP**	**The year after STEP-UP**

Serve as advisor for a science or engineering club	0	4
Serve as advisor for extracurricular science/engineering competition	2	3
Brought class to Ga. Tech for field trip or other special event	0	4
Conducted workshop for other teachers on modern physics and its applications	0	2

Table 13. Utilization survey-II

Frequency teachers did each of the following during fall semester.	**Not at all**	**Once or twice**	**Several (3 – 7)**	**Many times (over 7)**
Referred to your summer STEP-UP experience during class	--	8%	69%	23%
Discussed your summer STEP-UP experience with other teachers	--	15%	62%	23%
Discussed real-life engineering examples during science class	--	8%	54%	38%
Put materials acquired from STEP-UP program experience on display at school and/or classroom	14%	57%	14%	14%
Shared engineering education flyers obtained from the STEP-UP program	29%	43%	14%	14%
Discussed with individual students engineering or science careers	--	23%	23%	54%
Discussed during class engineering or science careers	--	23%	46%	31%
Shared engineering career video that you obtained from the STEP-UP program	29%	57%	14%	--
Communicated with your STEP-UP research faculty advisor	77%	23%	--	--

Formative assessment is conducted during the academic year workshops to identify those topics from the modern physics course that were incorporated in the high school classroom. Due to the time constraints and limited emphasis put on the modern physics topics in the state curriculum, the teachers did not have a chance to cover these topics extensively besides the wave concepts. However, almost all of them introduced the concepts and gave a few examples of engineering applications. Some purchased tools and demo sets to introduce some of the concepts to their students and adapt applied physics lessons to fit within the sate curriculum standards.

Other teachers reported that they were challenged to find time in their already packed curricula to incorporate the lesson plans developed during STEP-UP. The teachers explained that they were pressed to cover the topics from where questions on the general exams come and did not get a chance to further develop their lesson plans or incorporate other teachers' lesson plans. Table 14 provides information on the new material covered and lesson plans used by the summer 2005 participants.

Table 14. Utilization of lesson plans

Project or Assignment	**√ when required**		**√ portfolio**		
2005 COHORT	**Fall 05**	**Spg 06**	**Mine**	**Other**	**None**
Respondent 1 Castle Kits Electricity Project		**X**			**X**
Respondent 2 Investigate Capacitors		**X**	**X**		
Respondent 3 Creating an AM Radio Mems switches Patch Antennnas		**X** **X** **X**	**X** **X** **X**		
Respondent 4 Measurement lab	**X**	**X**	**X**		
Respondent 5 Build an AM radio receiver Building Capacitors		**X**	**X** **X**		
Respondent 6 Snell's Law leading to internal reflection		**X**	**X**		
Respondent 7 none					**X**

Over the past two academic years, 40 to 50% of the STEP-UP teachers arranged to bring their students to Georgia Tech for full day field trips. A typical visit consist of morning sessions with admission office staff, and campus tour followed by lunch at the Georgia Tech student center. In the afternoon, students tour the modern physic laboratories, and three to four of the Electrical and Computing Engineering research labs. These field trips have been very popular among the students as seen from feedback received from the teachers following their visits. After one tour, the STEP-UP teacher sent the following note: "My kids really enjoyed the trip. Most of my juniors plan on applying to Georgia Tech now. Some of the seniors wish they had and may transfer later". Another teacher passed along the following message several days after the field trip to the campus: "The students were very impressed with all aspects of the trip. Even today, 4 days later, they are still talking about what they experienced. There are some seniors/juniors that said that they now know that they want to attend Tech. Even the parent chaperones that went were very impressed. One parent emailed the principal about how wonderful the trip was and requested that we do this every year for her younger son that will be a sophomore next year". A list of all students who attend the field trips is maintained in order to track who of those students eventually enroll at Georgia Tech.

Summary

Over the past three summers total of 25 high school physics teachers participated in the NSF supported RET program STEP-UP. Based on several sources of feedback, all participants reported a high level of satisfaction with their summer experience. Teachers were very satisfied with the gained knowledge in modern physics topics and their engineering research experience. They were very excited of being part of a research group and learning how physics and microelectronics are related. They left the program with increased awareness and enthusiasm for the engineering field and careers. A majority of the teachers indicated that the program stimulated them to further encourage students to major in science or technology. What does stand out about the participants is the impact of STEP-UP on the desire to pursue further education. For example, six of the nine 2006 participants reported that STEP-UP experience increased their desire to pursue advanced or additional degrees. Seven participants said that STEP-UP influenced them to seek out other summer research programs.

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