Motivation, Mentoring, Manipulatives: a Two-Way Formative Process in Teacher Training Through a Knowledge Exchange Between Universities and Schools

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Abstract

A four-year project on the subject of Hybrid Electric Vehicles and funded by the National Science Foundation Graduate Teaching Fellowship Program in K-12 Education has facilitated an educational exchange between graduate students in physics, materials science and mechanical engineering, and middle school and high school teachers and students. The nature of the exchange is summarized by the "*M3: motivation, mentoring, manipulatives*" motto of the project. On one hand, the graduate students have been *motivated* to transmit their scientific knowledge that has been acquired through research, to the science teachers, while learning communication skills from the teachers. On the other hand, the teachers have been *motivated* to improve and update their science curriculum. This mutual *mentoring* interaction has been extended by the development of educational tools created by the graduate students, such as lesson plans that include in-class demonstrations, new presentations, "hands-on" activities (the so called "*manipulatives*"), online tools (a web-based Science-related "Question of the Week"), and teacher workshops (specific resources are given to the teachers, based on the actual research activities of the graduate students). The teachers contribute by providing continuous feedback to the graduate students. By using the subject of Hybrid Electric Vehicles as practical *motivation*, K-12 students have been introduced to fundamental concepts in mechanics, thermodynamics and chemistry. Through this project, the teachers' curricula have been updated and supplemented by a set of educational tools that are ready to use in the classroom. The graduate students obtained a broader educational experience, facilitating their understanding of the educational process and enhancing their potential as future educators. Finally, the K-12 students were able learn physical science from a new, informal, and

enthusiastic team of teachers with the aims of improving their performance and motivating them to pursue further education and careers in science or engineering.

Introduction

The exchange of knowledge between middle and high schools and the university has been always a technical and challenging topic in modern science education. The difficulty in transferring technical resources from the actual research fields in physics to the classroom have made this particularly difficult. New technological advances, derived from scientific discoveries, have also made no appearance in the schools, or they have been considered as marginal topics. On the other hand, most university graduate students and other researchers in physics, lacking experience in education, have traditionally not been involved in educational outreach experiences.

In the US, the National Science Foundation (NSF), through the establishment of a three-year "NSF GK12 – Graduate K12" fellowship, has provided a new mechanism to establish a direct link between the higher and the lower education systems. These fellowships are awarded to researchers at universities who propose new and innovative tools to fill this knowledge gap. One of these projects, at the Pennsylvania State University, is aimed at providing educational experiences in education to new graduate fellows, who will be tomorrow's educators, while providing innovative and research related instruments to teachers. It also aims to establish a highly communicative team comprising graduate fellows and teachers to share both classroom and lab experiences. This project involved graduate students and faculty from both the Physics Department and the College of Engineering, and the middle school and high school teachers from several schools. The goal of the project is to improve science education, and specifically to stimulate school students to pursue a career in science or engineering, and it is specifically oriented towards the technological implication of scientific discoveries.

The framework of the project is the development of the "Hybrid Electric Vehicle (HEV)" and high-power energy storage systems. This new technology, which is starting to appear in the automobile market, involves basic research in physics and chemistry, and applied research in chemical, mechanical, and electrical engineering. In this program, this technology is used as a motivation to introduce general elements of physics (mechanics, electromagnetism, and thermodynamics). This framework then supports the development of activities and tools for the classroom that are directly related to a real life experience. The project structure can thus be summarized by its motto: M^3: Mentoring, Manipulatives and Motivation.

Mentoring

The project for the past three years has involved eleven graduate fellows (both Masters and PhD students) from Physics and Engineering, three undergraduate students, and seven teachers. Each student is involved in a research program in their respective department. Each research program is at least loosely related to the HEV technology. In the case of one of the authors (NF), his research field involves surface science, specifically the study of gas adsorption on metal surfaces. Fellows in mechanical engineering are focused in vehicle controls, and energy storage (fuel cells). The areas of expertise of the fellows are quite diverse, ranging from highly technical engineering, to theoretical and fundamental science. This provides the school teachers with a wide range of possible technical preparations. The seven science teachers (four from middle schools and two from high schools), have backgrounds in science education, some towards biological sciences, some towards physical sciences. The age range is from 30 to 55 years old, with 71% male.

In most cases, a team comprises one or two graduate fellows and one teacher. The graduate fellows are expected to interact with the teachers every week. The discussion generally centers on ways to integrate the possible activities designed by the graduate fellows into the curriculum for the class. In this process, the teachers act as mentors with respect to the graduate fellows, guiding them in the development of the classroom activities. The usual procedure involves the teachers requesting a specific science topic to be the subject of an activity designed by the fellows. The fellows prepare the activity (in the form of a demonstration, a lecture, or a student experiment), to suit the teacher's needs. The teacher then makes specific adjustments to the language and vocabulary, the level of the material, the suitability for the class time and the ability to hold the attention and the interest of the students for the whole period. This process provides extremely useful training for the graduate fellows, who face the challenging task of rethinking a concept they learned in graduate school and turning it into an activity for K12. At the same time the fellows mentor the teachers, giving them updated scientific and technological information.

One of the main activities performed by the fellows in the classroom is a biweekly visit to the school to present the developed manipulatives (explained below) or class lectures. Another is the "Question of the Week" that is posted on a specially designed website (http://www.vss.psu.edu/nsf/qow/), targeted to the same. These questions are generally previewed by the teachers. The graduate fellows are in charge of the grading of the answers, and in posting comments. The teacher is responsible for checking the progress of the students, and to ensure that the comments are correctly assimilated by the students. Usually the topics of the questions are chosen based on a previous activity done in class, or on a scientific or technological event occurring during that time. The majority of the questions use the HEV framework. A typical question (targeted to a 7 grader) is:

Q. Hi, this is Mr. Nick. Hope you liked the Milk Carton Car experiment last week. You learned a bit about Potential Energy and Kinetic Energy. Here is this week's question: When you are riding your bicycle, you have some kinetic energy, because you are moving at a certain speed. At a certain time you start braking to stop. When the bicycle is stopped (no kinetic energy then) if you touch the pads of your brakes, they are hot. Why are they hot? Where does the heat come from? (note: this happens in cars too!)

A. The principle of energy conservation is involved here. When you are riding your bike you have kinetic energy. If you want to stop you must convert this kinetic energy to some other form of energy. In this case, you do "work" by applying a force on the brakes of your bike. The kinetic energy is thus converted to the form of heat. This is called dissipation of the kinetic energy because the friction of the pads on the wheels is a dissipative force. The same thing happens in cars too. In the HEVs the kinetic energy is partially converted into chemical energy, then stored in the battery. Those vehicles then have less friction on their brake pads, less heat is generated, and this means they reuse part of the energy that otherwise would have been dissipated as heat.

All of the "questions of the week" are collected and archived, so that a database is available for future use. The goal is to have the archive open to all the teachers, who want to continue to use the website when the M3 project is over.

The graduate students also act as mentors to the teachers. The main occasions for this are during the classroom preparation and during the yearly organized "teacher workshop" [1]. This workshop is a graduate course taken by the teachers to obtain a more extensive understanding of new science and technology. The workshop includes updates on the recent research of the graduate fellows, and it also introduces the teachers to the full range of activities developed by the graduate fellows during the year. Thus, the workshop provides new information, an overview and a summary of information that can be used in classroom. The final workshop of this project, held at the end of June 2003, was open to all the science teachers in the state of Pennsylvania. The aim was to distribute and share the experience gained during with this project and to stimulate the interest of new teachers to become involved in the next generation of this project [2].

A final moment of mentoring is realized with scheduled visits at the laboratories or locations where the graduate fellows perform their research. These visits are designed both as “field trips” where the school students can see the laboratories, and to present simply-explained ideas behind the scientific and technological. This is usually done in the form of demonstrations using toys or simplified versions of the equipment used. These visits also provide a means of looking for what research activities can be actually brought to the classroom.

Manipulatives

The testing field for the graduate fellows is the classroom. The classroom activities or lesson plans designed through the teacher-fellow interaction include demonstrations and short lectures given by the fellows to the students, under the supervision of the teacher. Initially those activities were designed and set up according to the teachers needs to fit the curricula. In time, they evolved to the form of “hands-on” activities, otherwise called “manipulatives”. The starting point in the development of the manipulatives was a suggestion from the teacher of a topic. Then the fellows would design a lesson plan, using the motivation and framework of the HEV technology. The fellows then guided the undergraduate students who were part of this project to develop a “hands on” activity, generally using simple materials that are usually available in the classroom. As an example, in the case of the energy conservation law, the middle school students split into groups of four or five students and were asked to build a small car using milk carton boxes, and then test the vehicle performance under different conditions (e.g. different weight, height, slope). Simple calculations were requested in the form of a worksheet, with some final analytical questions to summarize the activity. The complexity of the questions was adjusted according to general level of understanding of the class. The worksheets were then collected by the teacher who was responsible for grading them. For the overall project, the final grade assessment for the students was always decided by the teacher.

The level of understanding and the background knowledge of the students were taken into consideration during the development of the activities. For example, simple activities were designed for 7 graders (2^{nd} year of middle school), such as the "lemon batteries" (using lemons and metal electrodes, with an overview of electricity and circuitry). More complex activities were developed for high school students, such as "building a wind tunnel", or "flying an electric model airplane". The general HEV framework was used to provide focus to the projects. For example, in the case of the lemon battery, a great emphasis was given to the types of batteries used for automotive applications, trying to understand the differences from a quantitative point of view between the "lemon batteries" and for example the NiMH batteries used in the HEVs. The wind tunnel was a great opportunity to show the importance of resistive, speed-dependent forces in the laws of motion: they also affect the design of a vehicle, in order to improve fuel consumption. More scientifically oriented topics, such as phase transformations, were also linked to practical applications: for example, a demonstration where liquid nitrogen was used to induce a gas-liquid transformation provided the opportunity to talk about cryogenics as a feasible way to store gas fuel other than compressed in a vehicle.

An effort was made to give the school students the possibility of seeing some future technologies at work. For instance, we developed an activity using some educational fuel cells, with the hope of providing not only a clearer understanding of some simple chemical reactions, but also to show some of the possible breakthrough technologies of the near future.

Using the dual physical science and technology approach allowed us to enlist what are the main occupational differences between a scientist and an engineer. From an educational standpoint, this aspect is often not taken into consideration, since the general principles usually are studied without a sense of the practical application.

The entire set of manipulatives, including the lesson plans, the mini-lectures, and the hands-on activities, including guidelines for their preparation, and a list of materials and references, were all archived and posted on a public website as a resource for the teachers [3].

Motivation

This project was originally designed to motivate students of middle and high school age to learn physical science. This was done in steps, by starting at the middle school with the introduction of fundamental concepts, using a very informal and entertaining environment, and finishing at the high school with a more rigorous, detailed and analytical approach. The final goal is to have more students interested in a possible career not only in physical science, but also in engineering. The use of the "Hybrid Electric Vehicle technology" was felt to provide an effective framework and motivation in this project. The students generally were very responsive to this subject, with the practical examples less difficult for them to assimilate than the theory. This project therefore provided a motivation for students not interested specifically in the physical sciences, but with more practical interests who might consider a career in engineering or technology. An improvement in their score for the SAT test [4] was also considered to be a potential outcome from this project. Although no direct verification of such results have been possible, an overall improvement of the science curricula for the collaborating school has taken place [5].

The teachers benefited professionally by having their curricula updated through the interaction with the graduate fellows. The availability of educational tools, ready to use in the classroom, also provides a resource for future classes. This has also motivated the teachers, giving them the inspiration for new activities. The enthusiastic atmosphere of the teacher-graduate fellows has been a driving mechanism for pursuing more ambitious projects. In the renewal proposal of the project for the next four years, the teachers have been asked to be actively involved. The graduate fellows, most of them without any type of experience or training in education, and sometimes even without any specific interest in education, have learned how to transmit knowledge with the appropriate language and attitude, and they have also seen how challenging and rewarding a career in education can be. This overall positive experience was enhanced by the symbiotic relationship of the fellows and the teachers.

Conclusions

We have reported the results of a three-year-long project sponsored by the National Science Foundation, aimed at improving the interaction of graduate fellows and university researchers with middle and high school physical science teachers, through the use of innovative tools and cutting-edge technologies to design classroom activities (the so called "manipulatives"). The project resulted in a mutual mentoring and enrichment of both the graduate fellows, who obtained an "in the field" educational experience (making them possible future educators), and teachers, who have been stimulated to update and extend their curricula. Finally, the school students were the ultimate beneficiary of this project. Future improvements from the use of standardized tests and other assessments performed in the participating schools will eventually quantify the success of this approach.

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References

1. Of particular concern to Pennsylvania K-12 teachers are two recent acts of legislation: the continuing education requirements of Act 48, and Pennsylvania's Chapter 4 science standards. Act 48 requires that all certified educators complete six college credits, six credits of continuing education courses, 180 clock hours of continuing professional education, or any combination of collegiate studies, continuing professional education courses or learning experiences equivalent to 180 hours every five years. Chapter 4 establishes specific standards and assessment for K-12 education; the science and technology standards have only recently been adopted. All Pennsylvania K-12 teachers are required to accumulate continuing education credits. The organized workshop satisfied all the requirements of Act 48.
2. The approval for the next generation of this project by the National Science Foundation is still pending.

3. http://www.vss.psu.edu/nsf/
4. The SAT test is what used to be known as the Scholastic Assessment Test. This test is used to evaluate students' performance at the end of high school, prior the acceptance to higher education.
5. The reorganization of the science curriculum is ongoing in at least one of the schools.