Abstract

Penn State University has hosted a NSF sponsored GK-12 Outreach project for the past five years, and has just begun the second phase of the project. The Penn State project utilizes the talents of many science and engineering graduate students as teachers, mentors and role models for the K-12 classrooms. The project focuses on developing skills of students in the areas of science, technology, engineering and mathematics through the use of Advanced Transportation Technologies. The GK-12 students are invited to participate in research in various ways in support of Advanced Transportation Technology such as undergraduate/graduate student competitions like Future Truck and Challenge X. The quantitative assessment planned at the onset of the project proved inadequate. Therefore, as the project progressed, a more qualitative approach was used to gather information about the attitudes of students with regard to science. As the project progressed, qualitative assessment was used to gather feedback from GK-12 teachers and students as to the value of the efforts, and served as a supportive feedback mechanism to the graduate students. This paper will review the assessment tools used in this project, and will present the data collected for the phase I and phase II of the project.

Introduction

The Penn State GK-12 National Science Foundation (NSF)-funded Science, Technology, Engineering, and Math (STEM) outreach project to middle and high schools in northeast and central Pennsylvania has unfolded in two phases. The first phase, $M^3$ (Motivation, Mentoring, and Manipulatives) Hybrid-Electric Vehicle Educational Highway, was funded for four years. The ongoing second phase is commonly referred to as the NSF GREATT project, whose full title is, Track 2, NSF GK-12: Graduate Research and
**Education in Advanced Transportation Technology (GREATT).** Both projects place STEM graduate students currently in Ph.D. and Masters programs involving research in hybrid vehicle technology and advanced transportation systems in direct contact with students in middle and high school science and technology classrooms. The STEM graduate students, herein referred to as Fellows, devise “hands-on” lessons utilizing hybrid-electric vehicle technology that illustrates basic science concepts. The intent of the project was for the graduate students to act as a visiting teacher with the help and assistance of the normal classroom teachers. In addition to these direct teaching activities, the project also provided field trip experiences at the science labs at Penn State, an on-line question of the week activity, and a number of other science outreach efforts.

The initial evaluation plan provided for quantitative measures using a pre- and post-participation test approach as well as an attitude toward science pre- and post-participation survey. While information gained from surveys can be very valuable it was felt that the deeper, fine-grained information available from qualitative methods might better measure the attainment of the project goals in a useful manner. A change in middle school and high school students’ attitude toward science careers that is revealed by a pre- and post-participation attitude survey of all 7th graders might or might not be a result of this project’s intervention. Since the project involved changes to the experience of school students in the particular classes where graduate fellows used “hands-on” activities to convey important science concepts, it was felt that interviews and participant observation might better reveal the type of data desired than would a broad-based survey. Another focus of the project was the changes in the experience of graduate fellows as they participated in the project. Again, it was felt that qualitative methodologies might better reveal these changes.

The project collected and submitted standard quantitative reporting information to NSF using the NSF FastLane reporting system while appending the evaluator’s full report based on qualitative methods. The 2004 evaluator’s report was approximately 50 pages in length and contained information that supplemented the material submitted in the FastLane report. The evaluation was carried out using qualitative-based methodologies including: participant observation, open-ended interviewing, and document and artifact analysis.

This approach worked reasonably well for the first phase of the project, although project staff felt that more quantitative material was needed to provide greater context to the work being done on the qualitative side. With the second phase of the project, an expanded quantitative side has been added to the evaluation. This component is primarily based on the use of internet survey tools being set up in our existing project management software. In addition, we have been rethinking the theoretical focus used to frame the qualitative evaluation. As a consequence of this, a theoretical framework based around the concept of communities of practice and situated cognition is being implemented as a lens to be used to carry out the qualitative evaluation.
The purpose of this paper is to:

1. explore the findings from two specific investigative areas of the project,
2. have a brief look at what evaluation of a STEM outreach project might look like when carried out using a situated cognition perspective, and
3. discuss some of the tools of the trade of qualitative work.

History of Track 1 Project: Motivation, Mentoring, and Manipulatives

The track 1 project was titled M³: Motivation, Mentoring, and Manipulatives, and focused on the topical area of Automotive Technology Education. Graduate students who were studying such topics as fuel cells, hybrid-electric vehicles, batteries, and other automotive-related topics were involved in the project. So the mentoring of teachers and students in the classroom was comprised of transportation related topics. At the time, instruction in appropriate communication skills were provided for the graduate students and feedback on delivery helped to improve their teaching of the manipulatives in the classroom. All were motivated by the program to teach and learn from the experience and through the various manipulatives developed. These included the topics involving transportation as a way to “hook” the students interests. The K-12 student mentoring adopted many forms of education tools developed by the graduate students, which included lesson plans and in-class demonstrations, “hands-on” activities (the “manipulatives”), online computer tools (“Question of the Week”), and teacher workshops. By using transportation related topics as practical motivation, the K-12 students were introduced to various fundamental concepts in physical sciences, mechanics, chemistry, materials, and thermodynamics. Through the project, the participating teachers have had their curriculum supplemented by ready-to-use instructional tools in the classroom. The overall objectives of the project were to provide:

1. the graduate students with broader education experience,
2. the K-12 students with enthusiastic mentors of science in an informal setting with the aim of improving their performance and motivating them to pursue further education and careers in science and engineering, and
3. the teachers with educational tools as well as informal opportunities to work with graduate students who are involved in science and engineering, thus providing an opportunity to “ask the expert”\(^1,2\)

Track 2: Graduate Research and Education in Advanced Transportation Technologies (GREATT)

Under the second phase of the project, many of the same processes developed under the initial phase are being used to connect with the students and the teachers; in class presentations and “hands-on” activities, “question of the week” via the project’s web site, and the HEVIG: Hybrid-Electric Vehicle Interactive Game. Additionally, graduate fellows are making connections with students through schools’ open house events, science fairs, special hybrid-electric vehicle presentations at the schools, and a special web page development project. Some of the graduate and undergraduate students
involved in the project are also involved with the Future Truck and Challenge X (http://www.futuretruck.org/; http://www.challengex.org/), a college student project competitions which involve designing and preparing hybrid-electric vehicles with alternative fuels. It has been a useful tool to establish connections with the students by bringing the current engineering design challenges to the classroom and keeping the students posted on the progress of the competition.

The graduate fellows were also able to carry out a successful Summer Teacher Workshop in August 2004. With over 40 teachers in attendance, the workshop focused on the new phase initiatives in Advanced Transportation Technologies and included training sessions about automotive emissions, fuel cells, materials, sustainable transportation and energy, and a hybrid-electric vehicle and alternative fueled vehicle ride and drive event.

Finding Common Ground between Graduate Fellows and School Students

The effort by the scientific community to share part of their scientific knowledge into the mainstream public has been less than successful. Outreach activities developed within scientific research projects, although encouraged, have had limited extend. Graduate students are required to develop a set of verbal, graphical, and experimental skills that will allow them to share his/her findings with the science/engineering community. As they brought part of their expertise into the classroom, the GREATT fellows, being scientists and engineers in first place, found the task extremely more difficult than to bring their professional experience to the technical community. This difficult interaction was usually due to a lack of a common ground between the fellow and the students. What is the common ground needed to make the connection?

For example, in an activity designed to explain the working principle of a fuel cell, the fellows initially put a lot of effort into explaining as best as possible that the Hydrogen combined with the Oxygen were to produce electricity and water. Although this explanation was considered sufficient in a first year college classroom, the fellows found it inadequate for a middle school class. The atomic model as intended by the graduate students had to be represented visually to appeal to middle school students, with only the details relevant to the subsequent description of the fuel cell (the electronic exchange and the chemical reaction inside the cell).

This visualization and simplification process had to be applied also to the actual experimental setup in use. Scientific and technical instruments, although often based on simple concepts, tend to appear as very complicated objects to the general public. The level of sophistication that allows them to be practically useful in a research environment adds a layer of complexity that produces the feeling of distance and inappropriateness to the non-technical audience. The same is true when a counter-intuitive concept is proposed; a typical example is diffraction. Being a wave property, it conflicts with the common perception of atomic and subatomic entities (electrons, atoms, ions and photons) as particles. A diffraction pattern produced by the two slits illuminated by a monochromatic source of light (as well as electrons) challenged the common sense of
scientists a hundred years ago as well as all students today. Although diffraction is
commonly used to investigate properties of materials at the atomic level, the ideas behind
it are still obscure and not assimilated by the general public and even more so when
introduced in the classroom.

One of the authors’ scientific research projects deals with the use of electrons and atomic
diffraction to probe metal surfaces in order to understand their structure. In the effort of
designing an activity to introduce diffraction, these were the challenges:
- Can we use everyday materials to portray the same type of phenomenon?
- What tool should we use to simplify the approach to diffraction?
- When an appropriate tool is found, how should we described it—as a black box or
try to explain it?

The initial task was to identify a context whereupon to build the activity. Because atomic-
scale, nano-materials research can inherently be quite difficult to understand due of the
quantum mechanical implications, the fellows could not use any of the technical tools
used in this type of research in the classroom. Since light is the easiest way to portray and
to visualize an electromagnetic wave, a LASER pointer was used as a source, with the
inherent advantage to be sufficiently simple to handle by the students themselves. It was
also helpful to give an introduction of correlations and the emphasis of the analogies
between very well assimilated situations (sea waves for example) and the new concepts
the fellows were attempting to explain (light waves). With these analogies in place, every
concept was initially introduced within the known context (the wavelength of a sea waves
when dropping a stone in water), and then in the new one (wavelength of light). Using
the same approach, the students became used to comparing and visualizing their actual
laser apparatus with what would have happened for a sea wave. What would have been
an incredibly hard question to answer (“Why do we need to use the LASER instead of a
flashlight?”) instead became simple. This is because the students associated the idea of a
light from a flashlight as the waves produced by many stones dropped at the same time in
the water, while the LASER was associated with the wave produced by only one stone.

Diffraction was then introduced using the same approach. What happens if you drop two
stones at exactly the same time in the water? With the help of pictures and small movies,
the simple results of that experiment were presented (with less restrictive time constraints
that experiment could have also been performed in the classroom). With those results in
mind, the students were asked to try and imagine what would happen in a similar
situation of having a laser illuminating two slits. By analogy the students were able to
identify that a similar diffraction pattern would have been the actual result for both the
sea and the light wave. Similarly, the fellows challenged the students by asking them
what the diffraction pattern would have been in the case where the grating had more slits,
or wider or narrower slits. When the students were sufficiently confident, the fellows
gave them direction in order to produce a custom diffraction grid using a drawing
program and a laser printer. 3
By now, middle school students were able to make their own gratings and test them with the LASER light. Furthermore, they were able to tweak some parameters (slits size and number) to obtain the desired patterns. The initial challenge was to establish a parallel comparison between the diffraction experiments used as a tool to investigate of nano-scale materials and light diffraction from custom-made gratings. At the end of the activity the students were able to appreciate that although with different tools (light instead of electrons), they were able to create their “materials” (the grids) and to use the diffraction from the LASER to determine their properties; a procedure similar to what is regularly done in the lab. The immediate outcome of this and other similar activities was an overall appreciation of the different types of challenges that the fellows as scientists have to face on a daily basis.

The initial perception of a scientist or an engineer as a person dressed in a white-coat, working on obscure and mysterious formulas or with overcomplicated instruments, was changed by the vision of the students considering themselves as scientists or engineers. They envisioned that the approach the fellows were following in their research labs was conceptually similar to the one they had followed during the activities. In other words, they saw themselves as potential scientists and engineers. The fellows at the same time had an opportunity to approach their research topic from a different, equally fascinating perspective of a GK-12 student, recognizing the rewarding challenge faced daily by educators.

**Web Page Project**

Within the framework of the new phase of the project, a special joint GK-12 STEM outreach web page project was designed. The web page project was generated through a question from a teacher, asking about age-appropriate materials available to teach her students about Nuclear Energy and Clean Energy. An opportunity was uncovered after speaking with a professor at Penn State who teaches a general science class entitled, “Energy and the Environment.” For this class, the college students were required to design a web page. The professor agreed to ask them to make an additional page for their web site that was designed for an audience from 7th thru 12th graders. At the same time, the NSF project used this as an opportunity to research the perspective of the college students about scientists and engineers, as well as their opinion of the web-page project’s application to their learning of the subject matter. The data collected involved pre-project surveys and post-project surveys, as well as a minute paper. More information on this study can be found in the paper by Chapman et al. Overall, the web pages were well constructed and age appropriate for the GK-12 students who viewed them. The K-12 students seemed enthusiastic about the content, and happy to provide feedback to the college students. However, the college students did not seem to agree that designing a separate web page for an audience of 7th thru 12th graders had an impact on their learning. This suggests some misunderstanding of the directions to the college students, or a lack of relating the purpose of their work to what they learned in the class. It was clear from viewing their web pages that the college students did not clearly understand what inquiry-
based learning and active learning meant, although they were being taught with this method in the class and were asked the question in the surveys.

**Determining the Success and Outcomes from the Projects**

The next two sections serve to explore the experiences in the projects. In the first section, an understanding of situated cognition and community of practice is presented. The second section presents the qualitative tools used in the project along with some observations and discussion.

**A Situated Cognition and Community of Practice Lens for Evaluative Practice**

A situated cognition approach assumes that people have a variety of “ways of knowing” that are embedded in surprising ways in local conditions.\(^5\) The local conditions for learning include a diverse spectrum of local cognitive resources. These resources include not only print and other “standard fare” school-provided resources but also a broad array of non-school resources that flow from the interactions of specific groups of people who are not a daily part of school. These groups are assembled in what may be termed “communities of practice.”

The term community of practice simply refers to groups with face to face interaction who form an identity by virtue of participation in a specific activity set that members perceive as being shared and essential.\(^6,7,8\) A community of practice is similar to a cultural group whose members have a specific set of activities that they see as identifying themselves. Often a community of practice revolves around professional groups such as inorganic chemists working in industry or roofers who work on commercial buildings.

Admission as a member of a community of practice is normally highly regulated by the group and often includes a period of what Lave and Wenger have described as legitimate peripheral participation.\(^9\) It is important at this juncture to differentiate between a formal professional group such as AAAS and these informal, ad hoc groups that we are calling communities of practice. A professional association relies on external, formal representations for its existence such as a charter, by-laws, press releases etc.. A community of practice is primarily defined by the activity of its members as perceived by a member of that community of practice. The community of practice is perceived from the inside in terms of common activity by the members rather than primarily by its external, formal representations.

People normally belong to multiple communities of practice. Communities of practice often overlap in both time and space. An example of this overlap is the work of IT people and the work of scientists who are gathering remote data and must request the use of networks administered by the IT staff. The on-going articulation between the work of these overlapping communities of practices is a crucial area of situated knowing and relies on many, often-hidden mechanisms.\(^10,11,12\)
Situated learning can be thought of as learning that takes place from a specific standpoint or place. This place from which situated learning occurs is both social and physical. It includes relationships embedded in various communities of practice as well as the coordinates of a particular space populated by particular artifacts. These artifacts may be of traditional school-based types such as print materials found in textbooks and standard lab materials, or may involve actual materials and tools used in a specific community of practice. An example of the latter is the use of pH paper within the community of practice of graduate fellows in environmental science or in a commercial lab. The two concepts of situated learning and community of practice are linked. The premise of this approach is that situated learning (situated cognition) always takes place within communities of practice and that the particulars of relationships and the use of artifacts within these communities of practice are crucial to understanding situated learning.

Language use is a crucial feature within the landscape of situated learning. Not only does a particular form of language use, such as the use of slang or jargon, tend to define members and non-members of a community of practice, but the representational forms used within the community of practice that fill in the gaps of written and formal spoken communication are fundamental to the vitality and continuation of a community of practice. Attention to language use and representational practice in the sciences, technology, math, and engineering communities is a crucial element in the success of situated approaches to STEM outreach.

The authors are not saying here that situated learning is the only type of learning on the block nor is it necessarily the best. Didactic learning in a lecture format, or learning through repetition, for example, has proven to be an effective learning method as well. The point being that a situated learning perspective takes into account the nature of the activity of specific communities of practice and the coordinates of the particular physical spaces and artifacts that contain and assist these communities of practice. What are some of the consequences for project evaluation when using a situated cognition and community of practice perspective?

Here the authors briefly list and describe two of the many important consequences for evaluation of taking a situated perspective on a STEM outreach project. This portion of the paper is intended to stimulate discussion and questions and it is hoped that many other consequences will be noted by others involved in STEM outreach project evaluation. The first consequence involves the use of the definitions of project activity areas that are brought forward in the original grant proposal and provide the skeleton of any evaluation effort. The second consequence involves recognizing that a sensitivity to the growth in the quality of representational practice within and across communities of practices, such as school students and graduate science students, are as important as a mirror of the attainment of project outreach goals as are success on standardized pre- and post-tests or science and science outreach attitude surveys.
Project Activity Areas and Communities of Practice

The project activity areas are usually a redefinition or verbatim treatment of the text that formed a part of the original grant application. An important consequence of taking a situated learning approach is that these formal accounts of the proposed activity areas are carried out during the project by specific members of multiple communities of practice who probably had little or nothing to do with the grant. An understanding of the community of practices to which these participants, who are charged with carrying out the activities in the various project areas, belong becomes of prime interest in determining the context for making an evaluative judgment. The understanding of the communities of practice includes both its social and physical dimensions. As an example of this, the tensions that graduate teaching fellows hired by the project might feel as a result of allocating their time to the project and meeting the stated student contact hours as stipulated by the contract can perhaps be better understood when considered in terms of their membership in a lab research group. It is helpful to consider the organization of the lab group, and particularly of the attitude of advisors, regarding how many hours it takes to become a full fledged member of the community of practice of scientists in a particular field. This is not to suggest that the evaluator is looking for ways to justify high or low contact hours, but to suggest that the evaluative determination in the activity area of direct school contact hours can be seen within the context of a given community of practice, thus producing evaluations that are more generative in the overall context of both formative and summative evaluation.

Changes in the Quality of Representational Practice.

A second consequence for evaluation as a result of taking a situated approach is that the meeting of project outreach goals can sometimes be seen in the changes that occur in the ability of school students to represent science activities and careers and in the ability of science graduate students to represent scientific activity in language and terms that school students can grasp. These changes in representational practice are reflected in the use of a variety of social and artifactual communicative resources. Here the authors are suggesting that gains in these areas are not simply indicated by the results of surveys or short answers, but are demonstrated in practice by school students and by graduate science students.

For both indicators given above (evaluation of project activity areas in reference to the community of practice of participants and evaluation of changes in the quality of representational practice of school and graduate science students in the areas impacted by a STEM outreach project) the fine-grained methods of qualitative evaluation work to an advantage. In the following section the authors briefly review some tools used by qualitative and ethnographic researchers and suggest how these might be applied to the evaluation of STEM outreach projects.
Qualitative “Tools of the Trade”

Ethnographic and qualitative research and evaluation employ a tool kit of standard tools that differ in significant ways from those used in quantitative work. It is important to also recognize that differences in theoretical perspectives both within the qualitative tradition and between those used in quantitative and qualitative work determine the specifics and appropriate use of these tools. Here the authors would like to list and briefly describe four tools that have proved to be particularly helpful in the evaluation of the Penn State NSF GK-12 project. These are participant observation, unstructured interviews, document and artifact analysis, and sensitivity to language issues.

**Participant observation**

Participant observation is a technique pioneered by anthropologists who lived in a foreign culture for a number of years, learned the language, and as much as possible participated in the everyday activities of the group they were studying. Participant observation in this extreme form is not needed in the evaluative work of STEM outreach projects. The basic idea here is that the researcher becomes the research instrument. This is accomplished by coupling the heightened awareness of the situation that comes with participation with a careful notation process. This process can consist of mental notation to be written down later or transcribed during the activity. Observations become much more powerful with participation because the participant now has something at stake by virtue of being involved. This heightened awareness often extends to an awareness of the emotional and tacit component of activity that would be otherwise hidden when a person simply observes by using a check sheet or notes while sitting off in a corner. For STEM outreach projects in schools with a “hands-on” lab component, providing help in the “hands-on” portion of the lesson is often appropriate and welcomed by visiting graduate students and teachers alike. Any level of participation includes a responsibility to be knowledgeable enough about the activity not to cause a serious problem and to know when to call for help.

**Unstructured Interviews**

Unstructured interviews differ from survey work and work with interview templates in that the interviewer is not trying to duplicate the questions asked for each person interviewed. There are serious questions concerning the ability to maintain identical questions and interview situations in a structured interview. In an unstructured interview the researcher or evaluator is pursuing certain themes that have emerged in previous interviews and from other methods of evaluation used for the project. These themes are explored in the interview as the person being interviewed develops them or as new ones emerge. Often a theme that seemed important may elicit little or no response and then suddenly a new theme will emerge with an obvious punch that catches the researcher’s attention. This is a time-intensive method as the length needed to really get started with an interview of this type is usually at least 30 minutes. Once over the initial point at which a rapport is established, it is surprising and satisfying to see how much a person in
an unstructured situation will share about their feelings and goals and views on different aspects of the project with very little or no prodding. It is perfectly acceptable when using this technique to go back and do more extensive interviewing of the same people provided time permits, and an important theme has emerged in later interviews with other people. Taping is helpful for the record even if the interview is not transcribed verbatim. Few people are aware of the tape recorder after it is turned on; however, permission to tape is always obtained before starting. Clear documentation of the people who have been interviewed, the length of the interview, and notes on the circumstances of the interview together with a reference to the tape are important for citation purposes and for keeping track of pseudonyms.

**Document and artifact analysis**

Documents include the formal (letters, public e-mails, press releases, grant proposals, school district newsletters, etc.) and informal (shared personal e-mails, handwritten notes, writing on the blackboard, and other less permanent material) written material that surrounds and infuses a project. Artifacts include the devices such as computers or scanners, material for “hands-on” activities, the lab space at a university that is being toured by middle school students, lab equipment etc.. A selective listing of these, and notes on how they fit into some of the evaluative or research themes that one has seen emerging in one’s other work, will prove to be very fruitful at the data analysis stage. The selection of documents and artifacts to examine must be made on the basis of the sensitivity the evaluator has developed for the practical and theoretical issues in the evaluation. At the start, there is not much to go on and one must rely on intuition and chance encounters with documents and artifacts. Later, the selection process will be more focused as themes emerge.

**Sensitivity to language use**

This last tool is more a way of hearing rather than a specific set of procedures. The core idea is that much is revealed by the way people use language in everyday speech and that one doesn’t have to be trained in linguistics or conversation analysis to make use of this avenue of understanding. A starting point is to ask if there are ways in informal speech that different communities of practice tend to distinguish themselves. Listening attentively to middle school children talk before a graduate fellow starts the lesson can provide insight into how, for instance, “scientific type speech” is received by classmates. The way questions are framed and the words chosen for the questions that are addressed to the fellows, as opposed to teachers, can also be informative. Informal fellow-student interaction at field trips can often shed light on other issues that may have emerged as themes in other evaluation work on the project. Another resource for developing this language sensitivity is to visit the labs the fellows work in and observe how they discuss the equipment they use in their work when they are speaking informally and personally among themselves, or with an outside individual.
Conclusions and Future Plans

The Penn State graduate students who participate in the NSF GK-12 program have learned that their science and engineering training achieved over many years of study is not something that is easily taught and translated to K-12 students. Their training was accomplished through learning the common languages spoken by scientists and engineers, such as the language of the metric system and of the periodic table. However, speaking the language to other scientists and engineers is not the same as speaking the language to K-12 students. The NSF Fellows have learned ways to find common ground with the students in the classroom in the same way that they find common ground with other scientists and engineers—through the language of the “community of practice”.

The evaluators of the project have determined that finding the successes of the program are not a function of a quantitative method alone, but involve the use of qualitative tools to understand the quantitative data. In fact, it may be that the qualitative tools actually tell more about the findings and evolving themes of a project, as demonstrated in the web page project artifacts. The authors have listed and discussed some the tools used by the evaluators of the project. These are by no means the only qualitative tools that can be used, but ones that the evaluators of this project have found to be effective. The evaluators also suggest that there are consequences to following a strict evaluation plan as outlined in the grant proposal, as strict adherence may lead to closing the minds of those being evaluated from other specific outcomes gathered from a freedom of thought and expression.

Finally, the authors are left with a few questions for future research:

- Do all the graduate fellows speak the same “language” of science and engineering when in the classroom?
- Should there be a common approach?
- Are the teaching styles of each fellow the same?
- Are all the fellows able to establish common ground with the students?

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Bibliography


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