

Teaching Inquiry and the Impact of Performance Based Assessments

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Abstract

Inquiry is central to the learning of science. It has been described as “an approach to learning that involves a process of exploring the natural or material (or social) world and that leads to asking questions, making discoveries, and rigorously testing those discoveries in the search for new understanding” [1]. This article explores the impact of teaching inquiry as contrasted with doing projects and laboratory exercises. Learning through inquiry requires one to have problem solving skills. The authors discuss some of the approaches that they used to teach problem solving skills to High School Physics, Physical Science and Pre-engineering students and some authentic performance assessment methods that were used to provide effective and timely feedback to the students. We also discuss the change in the teaching philosophy of the teacher during this process and the implications of these changes for future students.

Background on PROBE Project

Scientific inquiry, according to Dow [2], has its roots in the “inherent restlessness of the human mind”. He also said that “the basic human trait that has ensured both our survival as a species and our continuous cultural evolution is our curiosity”. Human progress is a direct function of inquiry as is borne out by history. From ancient Greece, to the Renaissance and to the Age of Enlightenment this passion for inquiry, fueled by questioning and debate has been passed on to the twenty first century scientist. Students need to be taught how to develop the skills necessary to think like scientists and engineers. The development of solid scientists and engineers requires both the learning of concepts and the acquisition of inquiry skills such as scientific thinking and problem solving. Therefore, because inquiry skills are so important, cultivating them should be a significant part of the education process.

Rankin [3] makes the following very important point, “Although inquiry based teaching is indicated as a central feature of science education in both the National Science Education Standards [4] and Benchmarks for Science Literacy [5], neither document recognizes it as the sole approach. Science teaching should encompass a wide range of methods. Even within the realm of inquiry teaching, there is a wide spectrum of approaches.” So it always comes down to the teacher deciding on the best balance that is appropriate for a particular class. This therefore means that authentic inquiry can successfully and consistently be used only if the teacher is willing to invest the time and effort required to create an environment in the classroom that is conducive to and supports inquiry based learning. Understanding the process skills that a scientist or an engineer needs to solve real life problems helps the teacher to know which skills need to be taught and/or practiced in the science classroom in the context of the appropriate subject content.

A number of myths have developed over time about inquiry and many have been wrongly attributed to the National Science Education Standards, but these have been discussed in detail in the literature such as by Rankin [3]. Some common ones include the following

1. *“Student engagement in hands-on activities guarantees that inquiry teaching and learning are occurring”*
2. *“All science matter should be taught through inquiry”*
3. *“True inquiry occurs only when students generate and pursue their own questions”*

Assessment of inquiry based learning is carried out differently from that of lecture based learning and is considerably more involving for the teacher because of the “openness” of the student learning process. While the teachers set the overall learning goals, they need to determine the learning progression of each student and provide appropriate feedback that will enable the student move to the next steps in their learning. This assessment is formative in nature and should be given back to the student in a timely manner. As noted by Harlen [6], “In order to be useful, formative assessment must cover the important outcomes that are intended in inquiry learning. That is it must be concerned with the process skills and with the understanding of scientific ideas. So the outcomes of inquiry learning have to be identified, and it is essential to know what is meant by progression in each of the skills, attitudes and areas of understanding.” The model used to demonstrate progression in inquiry learning is that from Inquiry and the National Science Education Standards [7] see appendix A.

The PROBE Project

The GK-12 Partnerships for Research Opportunities to Benefit Education (PROBE) project was developed by the Joan and James Leitzel Center for Mathematics Science and Engineering Education (Leitzel Center), at the University of New Hampshire, to enhance and encourage the use of the Inquiry Process in science classrooms throughout New Hampshire’s High Schools. This would be done within the projects four primary goals of

1. *Guiding and encouraging teachers to experiment with new pedagogical techniques*
2. *Promoting, empowering and engaging students in science*
3. *Including engineering/design skills within the curriculum*
4. *Strengthening and connecting the mathematics within science classrooms*

The model selected was that of pairing up nine science teachers with nine graduate students (fellows) from the university's science and engineering colleges. A tenth fellow who was a graduate student in mathematics was selected to work with the fellow/teacher teams to strengthen the connection between science and mathematics. The teachers were selected from nine local schools and represented almost the whole spectrum of science that is offered in high schools from remedial introductory courses to college preparatory courses. Also the nine schools were selected in such a way as to reflect a wide variety of school demographics within the state, from large urban schools to small rural schools. This article discusses the teaching of inquiry and performance based assessment at two different schools viz.:

- *Pittsfield Middle High School (2004-5 academic year) – Small/rural with a total student population of about 350 for grades 7-12*
- *Somersworth High School (2005-6 academic year) – Medium/urban with a total student population of 700 from grades 9-12*

The classes involved in the project at these two schools were

Pittsfield Middle High School

- *Senior Physics*
- *Sophomore Physical Science (Tech prep and college prep)*
- *Pre-engineering*

Somersworth High School

- *Freshman Honors Physical Science*
- *Freshman Physical Science*
- *Senior Physics*

The fellow spent two days a week at each of these two schools working with the teachers in their classrooms developing new and enhancing existing inquiry based techniques to improve student learning. Teaching in a sense is a very lonely profession, because once class begins the teacher has very limited contact with adults especially professionals from other fields. One of the teachers said that, “teachers are hungry for professional conversations”, and the fellow brought a valued perspective to everything from prioritizing objectives to highlighting the kinds of thinking students exhibit. This meant that the relationship between the fellow and teacher had to be one of mutual respect and trust and they needed to work as a productive team. To help in creating these optimal teams, the Leitzel Center arranged a series of activities over the summer to among other things:

- Introduce inquiry based learning models
- Create Teacher/Fellow teams
- Review the curriculum to be covered
- Develop start up inquiry activities
- Enhance team and group bonding

This paper presents perspectives from each of the two schools in the areas of teaching inquiry or problem solving skills within an engineering context. Specific engineering and/or science inquiry activities are presented. Finally performance based assessment and its impact on the teachers themselves and consequently their students are discussed.

Teaching Inquiry (Pittsfield Middle High School)

All around the tenth grade science classroom, students are busy creating small DC motors in an attempt to pull the most paperclips. The teacher will be grading heavily (40%) on their “engineering,” using classroom observations and the journals students maintain as they work. According to the assessment rubric, maximum points will be awarded in “engineering” if “Class/journal work shows evidence of careful thought before & during construction. Many small improvements were considered in an effort to improve the device during trials. Journal identifies several specific variables you tested.”

Some students are doing very well; they logically consider improvements to every facet of the motor in order to maximize performance. They are “good problem solvers.” Usually, these students enjoy tinkering with things around the house or garage. These are the students who will be encouraged to pursue engineering.

Unfortunately, too many students are not good problem solvers. Journal entries like “Today I worked on my motor,” increase the difficulty of providing quality feedback. Entries such as “Everyone else’s works but no one will tell me how to make it go,” are common. These students are frustrated time and time again. Consequently, they are not as likely to pursue engineering or to be as engaged in any required engineering-related courses. Often, the students end up copying designs from peers, or bringing in an “overnight success” most likely completed with someone else doing the “engineering” then trying to explain it to the student. However, students know they did not “figure it out,” and express opinions like “I’m not good at this stuff.”

The teacher is frustrated. In attempting to incorporate more pre-engineering into her science classes, to give students more practice with authentic problem solving projects, she seems to be doing more “filtering” than actual teaching. She’s a good teacher, but she can not seem to pinpoint the cognitive processes the students are lacking. The teacher also co-teaches a pre-engineering course with a technology education teacher who has a background in engineering. The two of them separately assess journals many times a semester and have nearly perfect correlation. Clearly, lack of recognition of good problem solving is not the difficulty. The teacher feels ineffective in offering feedback or structuring classes to improve the elusive “engineering” thought process skills. Feedback is fundamental to learning. Although students receive some feedback from the success or failure of the project itself, the teacher knows the experience could be so much richer if she could just figure out how to TEACH the problem solving instead of only having students DO it.

Then, the teacher learned of the UNH PROBE Project – a mechanical engineering PhD candidate in the classroom two days a week without any pre-packaged outside curriculum attached! What a great opportunity to get inside the mind of an “expert thinker” in engineering problem solving!

Simply stated, the science teacher did not understand the heuristics of engineering. How do engineers tackle a design problem? Having completed a traditional college teacher preparation program, the science teacher had never studied the thought processes of “engineering,” or even taken an engineering course. Teachers are skilled in designing lessons and assessments to promote learning, but they must be able to identify the desired learning outcome. For example, extensive research has been done to identify strategies and thought processes used by strong readers vs. poor readers. To improve reading skills, teachers offer direct instruction, practice and feedback on those strategies. While significant practice is required, poor

readers hardly benefit from only being given more to read. To improve student engineering skills, students must learn the thought patterns of an engineer, not just do more engineering projects.

Over the course of the PROBE Project, the teacher and the engineer developed a partnership centered on the question “How does an engineer think about ...?” Although engineers are not accustomed to “thinking about how they think,” metacognition is the daily bread of teachers. Numerous studies have shown the discrepancy between science teachers’ beliefs in the value of inquiry, and the practices used in the classroom. In this case, the teacher wanted to teach the inquiry skills related to engineering, but simply did not understand them well enough. The process of learning what it meant to “think like an engineer” also caused the teacher to re-examine her understanding of the heuristics of “science” in general.

Early in the project, the teacher fired numerous questions at the engineer related to the motor project, the first “engineering” project of the sophomore physical science course. She laid out the task of the project and asked the engineer to talk aloud through his approach to the problem. The engineer began discussing a “parts analysis” and identifying variables for “tests” and determining “success criteria”. It would be rather naive to believe this immediately clarified the kinds of skills the teacher should be aiming to develop in her students – it took time, trust, and the developing partnership between the two. The teacher was not immediately convinced of the time vs. benefit ratio of some of the engineer’s preparatory work, or which ways of thinking were specific to that engineer vs. those that would most benefit a majority of students. However, as she began to recognize the specific skills desired in the students, she began to assess those skills more directly and to give more weight to those results. For example, she broadened a test question used to assess student understanding of a battery lab to include whether they could set up a simple scientific test for which they had not previously been given a procedure or data table (figure 1). Whereas before the project, similar questions had simply been added into an overall test score, this time the teacher noted how each student, by name, responded to the question. She was shocked by how many “good students” had no concept of which quantities should even be involved in the test! Her attention to that specific question demonstrated the first small changes to the value she placed on inquiry skills. No outside research impacts a teacher as strongly as the evidence she sees in her own classroom. With those results, the teacher resolved to dramatically increase the emphasis on basic scientific inquiry. About a month into the PROBE Project, preparing the motor project, she

Example test question:

You have vinegar, water, cups, a DMM & wire leads, and tin snips (for cutting metal). You also have pieces of copper, silver, aluminum, and nickel.

You want to know if/how the size of a metal electrode affects the voltage of the cell. Briefly explain your experiment, being clear about what you’ll change and what you’ll keep the same... Make a data table for your experiment, labeling the columns/rows. (Clearly, your data table won’t have numbers yet because you haven’t conducted the experiment!)

Results from college prep sophomore class:

9 students completely missed the point

7 students understood they’d need to change the size, & measure voltage, but could not create a coherent table

2 students received full credit for response

Figure 1 Example test question and sample results

made substantive changes to the structure of the journal and to the initial presentation of the project to the class. Constraints were added to the project, limiting the variables to those directly connected to the quarter's topic of study (electricity and magnetism). Most importantly, as the engineer worked with students on their projects, the teacher was able to directly observe the different heuristics between the expert and the students. The continuing changes to her understanding of the desired outcomes, and growing belief in the validity of those outcomes, naturally caused her to change her instructional and assessment practices. The changes the teacher saw in her students gave the PROBE Project greater credibility in her eyes, prompting more trust and even greater changes, gaining momentum throughout the year.

As the next school year began, the differences in the teacher were dramatic enough that every lesson plan was different. Initial lab activities emphasized creation of a data table, requiring that students be able to identify the independent and dependent variables in a described test (although that specific vocabulary was not emphasized). Following the teacher's demonstration of the basic motor design, students wrote a description of their task, including a sketch of the motor labeling each important part. For each part, the students created a two-column list of "things they could/could not change." They identified concepts they had studied that connected to each potential variable. Students received feedback from the teacher as they worked, as well as from peers in their collaborative group. As they worked, they tested the impact of each "thing" they changed, generalized the results, and specified what design changes would be prompted by those results. The differences in the classroom were dramatic. The most pronounced change was seen in the lowest-achieving students. Given a much clearer understanding of how to figure out

what to try when the motor didn't work as well as desired, not one student quit in frustration or brought in a suspect project created overnight. (See Figure 2 for a sample journal entry from a struggling student.) It is worth noting that the journal only served as a convenient written form for the kinds of thinking expected for each entry, allowing for asynchronous/delayed feedback from the teacher. The nature of the immediate conversational feedback in the classroom also changed to reflect these thought patterns. Importantly, because students model behavior on the teacher, the nature of student to student conversations also began to change.

Today my motor is still working. Erin noticed that the magnet has a lot to do with the speed of the motor. We did a couple of tests to find out whether the position of the magnet had anything to do with how many paper chips we pulled.

Positions	Trial 1	Trial 2
Vertical	Fast	Fast
Horizontal	Faster	Medium
To the left	Medium	a little faster
To the right	Medium	a little slower

Vertical Horizontal To the left / Right

Figure 2 An example journal entry of a struggling student

If all the changes were summed up in one sentence, it would be “Teach students to view their world in terms of variables that impact one another in definable ways.” The statement sounds obvious enough, but in today’s atmosphere of standardized testing, it is easy for a teacher to become hyper-focused on content alone. The problem solving skills students need in order to be successful with engineering design tasks are one subset of the “inquiry” skills students need in order to think and investigate as scientists do. Students must repeatedly ask themselves what variables might impact the success of the project, then design, conduct, and analyze experiments to answer those questions.

Teaching Inquiry (Somersworth High School)

The PROBE lead teacher at Somersworth High School had only one year of teaching experience at the point when he got involved with the project and previously worked in academic genetics research, where inquiry was practiced abundantly. This teacher was pleased to begin developing inquiry-based lesson plans early in his teaching career. Major challenges included matching problems to student skill levels, incorporating a wide variety of inquiry problems across the curriculum, and assessing the learning of problem solving skills.

For the most part, this teacher relied on one-on-one conversation to provide feedback to students on their inquiry skills. For each student the teacher tried to suggest two or three things to work on beyond the student's current level of performance. Examples included: use a variety of sources when researching a problem, ask a question about the problem, ask a specific question, ask a more challenging question, use as few words as possible to explain something, and prove it. Occasionally, general corrections or affirmations were given to the class as a whole, such as “You could have picked more challenging problems” or “I learned a lot from your presentations.”

Performance-based Assessments (Pittsfield Middle High School)

Design tasks like the motor project are just one form of performance-based assessment. As discussed earlier, their impact on student learning depends on the nature of the feedback received during and after the process. Before joining the PROBE Project, the teacher had also used a few “lab challenges” to assess practical lab skills and content understanding (Figure 3). These challenges usually followed more traditional instructional activities to teach the content. Although students often wrote the procedure for labs, the

Example Rotational Equilibrium Lab Challenge (Senior Physics):

Each student has an individual apparatus consisting of a meter stick, 4 sliding mass hangers, and a fulcrum. Students are allowed to make any measurements deemed necessary, and to run trials to verify their understanding of the calculations.

For the challenge, the teacher specifies three of the four masses, and locations of all the mass hangers. The student must prepare the fourth mass such that the meter stick will be in rotational equilibrium. This is a pass/fail assessment.

Figure 3 Example of a Lab Challenge

teacher defined the purpose and general set-up.

One of the changes prompted by the PROBE Project experience was that the teacher placed more value on having students determine what questions needed to be investigated. However, there continues to be specific curriculum content that must be learned from each lab experience. As a result, some “lab experiments” are shifting toward “outcome-based investigations.” The teacher specifies the lab challenge that must be met at the conclusion of the lab time. The students must determine what quantities might be relevant, how each can be measured, which must be held constant, and what relationships or values must be determined. They design, conduct, and analyze experiments as necessary to address the challenge. (See Figure 4.)

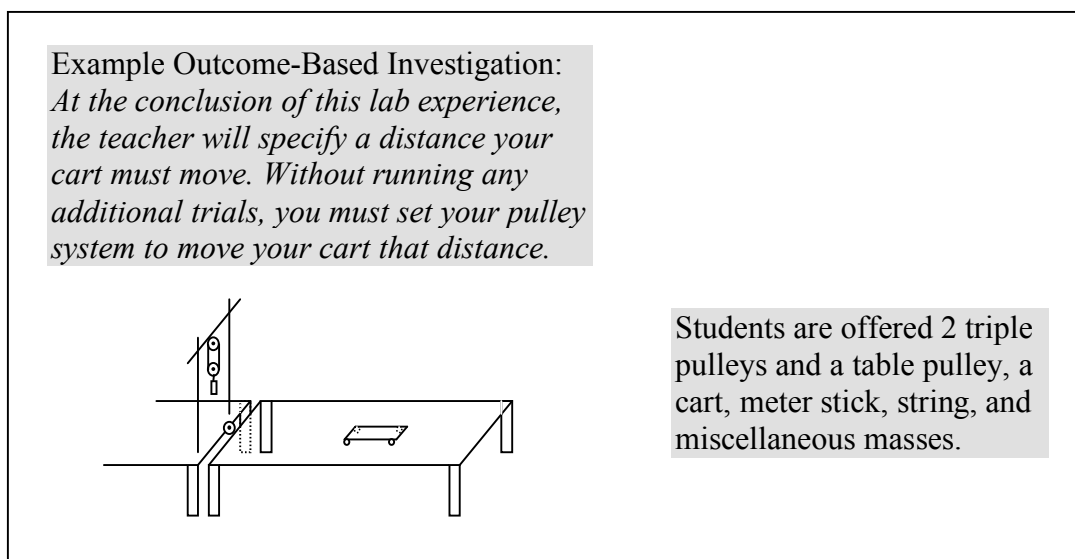


Figure 4 An Outcome-Based Investigation

Feedback is given throughout the process, as well as on final lab reports.

Performance Based Assessments (Somersworth High School)

An example of an investigation performed by Physical Science students involved determining the change in thermal energy of a chunk of metal using a calorimeter made from two styrofoam cups, a sheet of aluminum foil, and a thermometer. The instructor demonstrated how to make and use the calorimeter. Students were given a set of parameters to determine: mass of water in calorimeter, mass of unknown metal chunk, change in temperature of water, specific heat of water, change in thermal energy of water, and change in thermal energy of sample. Data was reported as part of a formal lab report. They were to develop their own procedures for determining these parameters. The biggest challenge to students was to link what they had learnt about conservation of energy to the energy exchange that was occurring between the piece of metal and the water.

Another was that of a long term project undertaken by Physical Science students that lasted about three weeks began with students picking a topic of interest from their textbook. They then were asked to describe how a technology related to their topic affected society.

Students were given a week to complete the written part of this assignment, including two 45-minute periods of library research time when students could receive feedback on their research from their teacher and the PROBE fellow. The feedback given was in the form clarifying questions and questions intended to narrow down the research to something that could be done within the given time. Students were then asked to develop a 2-minute PowerPoint presentation describing the technology that they had researched on. They were allowed class time to gather illustrations and use the school computer network to build their presentations. The teacher assigned a grade to the written portion of this project based on adherence to guidelines, diversity and precision of references, depth of technical explanation, and creativity in offering a solution to a problem. Students as well as teacher graded the presentations based on whether the listener could understand the speaker's technical explanations and how interesting the listener thought the presentation was.

Conclusion

To improve the inquiry skills of students, they must learn the thought patterns of an engineer or a scientist and not just do more engineering or science projects. The teacher needs to create an environment in the classroom where inquiry can be cultivated. Appropriate evaluation and timely feedback are essential to help the students learn the concepts and skills that are being taught.

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References

1. National Science Foundation (2000). An introduction to inquiry. In *Inquiry: Thoughts, Views and Strategies for the K-5 classroom*. Foundations, Volume 2, Preface and Introduction. <http://www.nsf.gov/pubs/2000/nsf99148/htmstart.htm>
2. Dow, P., National Science Foundation (2000). Why Inquiry? A Historical and Philosophical Commentary. In *Inquiry: Thoughts, Views and Strategies for the K-5 classroom*. Foundations, Volume 2. pp5-8. <http://www.nsf.gov/pubs/2000/nsf99148/htmstart.htm>
3. Rankin, L., National Science Foundation (2000). Lessons Learned: Addressing Common Misconceptions About Inquiry. In *Inquiry: Thoughts, Views and Strategies for the K-5 classroom*. Foundations, Volume 2. pp33-37. <http://www.nsf.gov/pubs/2000/nsf99148/htmstart.htm>

4. National Research Council, (1998), National Science Education Standards, National Academy Press, <http://www.nap.edu/>
5. American Association for the Advancement of Science, Project 2061, Benchmarks for Science Literacy, 1993. <http://www.project2061.org/publications/bsl/online/bolintro.htm>
6. Harlen, W., National Science Foundation (2000). Assessment in the Inquiry Classroom. In Inquiry: Thoughts, Views and Strategies for the K-5 classroom. Foundations, Volume 2. pp33-37. <http://www.nsf.gov/pubs/2000/nsf99148/htmstart.htm>
7. National Research Council, Inquiry and the National Science Education Standards: A Guide for Teaching and Learning. National Academy Press: Washington, DC, 2000.

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Appendix A

Essential Features of Classroom Inquiry and Their Variations

Essential Feature

Variations

1. Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
2. Learner gives priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
3. Learner formulates explanations from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to use to sharpen communication	Learner given steps and procedures for communication

More ----- Amount of Learner Self-Direction ----- Less
 Less ----- Amount of Direction from Teacher or Material ----- More