Non-directed Research Projects in the High School Classroom

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Overview

Students whose only encounter with scientific "research" is the directed laboratory experiment often fail to grasp fully the complexity encountered and procedures utilized by research scientists in authentic laboratory settings. They rarely have an understanding of research protocol and experimental design. It is not often that they have to think through an experiment from beginning to end, taking into account the need to hold certain variables fixed while others are manipulated.

During this past school year the lead author had an opportunity to teach one section of a yearlong high school physics course at Illinois State University's laboratory school. Following units on kinematics and energy, he had the students design and carry out non-directed research projects dealing with the conservation of energy. One goal of using a non-directed approach was to acquaint students with some of the procedures employed by physicists as they conduct research. Another goal was to provide for some form of assessment of procedural knowledge. There was also the hope that some of the less gifted students would demonstrate competencies not otherwise displayed in more traditional settings and assessments.

The coauthor assisted with an assessment of student perceptions and attitudes. He was a physics teacher education major enrolled at Illinois State University at that time. The co-author prepared, administered, and performed data reduction on a non-scientific attitudinal survey, the results of which will be described qualitatively in the body of this article.

Procedure

The project began with the instructor assembling mixed-ability groups to investigate various elements of a fundamental scientific question, "Is energy conserved when changed from one form to another?" Groups consisting of four students were assigned one of six research questions dealing with conversions between the potential energy of a spring (PE_s), the potential energy due to gravity (PE_g), and kinetic energy (KE). Prior to the beginning of the project, students had been introduced to the concepts and formulae for PE_s, PE_g, and KE. Conservation of energy had not been discussed.

Students were given hints to help them determine whether or not energy was conserved. For example, in the case of a frictionless, simple pendulum where PE_g is converted to KE, one could write

$PE_g(\text{top}) = KE\ (\text{bottom})$

if energy is conserved. Similarly, if the difference between PE_g(top) and KE(bottom) is non-zero, then it could be said that energy is not conserved as written.

Each student group was charged with developing a research protocol and an equipment design to answer that group's research question. Students were given access to the lab school's physics storeroom to determine what sort of material was available for use in the experiment. If an item of classroom equipment was available to a limited extent because of use by other groups (an air track for instance), then

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student groups had to negotiate with one another for access to that piece of equipment. If a piece of equipment was unavailable or needed to be constructed, then the description or design of that apparatus had to be provided to the course instructor who had access to both a university physics store room and a machine shop. When students needed special but easily obtainable items like toy cars or clay, they purchased these items or brought them from home.

Research protocols were to include a working theory, and a procedure for the collection and analysis of data. Parts of several class periods were used by students to come up with research protocols and experimental designs. Procedures, along with an equipment list, were then submitted to the teacher who determined if the strategy was both safe and "doable" (but not necessarily correct) as proposed. Once all the projects were approved and materials in place, the lab work began in earnest. One week was set aside for the research.

At the conclusion of the laboratory work each research group was required to write a single project report about their findings. This was followed by a group presentation of results to all other research groups. The class presentation, like the project report, had to fully detail working theory, procedures, data collection and analysis, error analysis, and conclusion.

Project Designs

PE_g to PE_s: This research group had a rough start. At the outset the students tried various unsuccessful procedures to get a metal ball to drop vertically and hit centrally on and compress a long spring that had a small spring constant. After a period of trial and error they came up with a method for centering the ball over the spring -- the ball was dropped down a vertical guide tube that was centered over the spring. Once this procedure was worked out, it became evident to the students that it would be difficult to measure the compression of the spring, the upper half of which was confined within the opaque guide tube. The students independently came up with a procedure for relating the motion of the midpoint of the spring to the entire motion of the spring. The students concluded that energy was conserved within the limits of their experimental uncertainty.

PE_g to KE: This group chose to roll balls down a flexible toy racetrack, over a horizontal table top, to a landing some distance from the point on the floor directly below the table's edge. The students used horizontal displacement and their knowledge of particle motion to calculate the speed of the ball as it left the table top. Different balls rolled down the incline gave different results. Some balls (larger, more massive) showed to a greater extent that energy was not conserved; other balls (smaller, less massive) gave much better results but still indicated that energy was not conserved. The students finally came to the realization that some of the PEg was wrapped up in rotational KE, a concept that had not been touched upon in class.

PE_s to PE_g: One group of students had the ISU Physics Department model maker prepare a Plexiglas "cannon" with a triggering mechanism to fire a small ball bearing. The cannon was aimed vertically and the ball was projected upward using a compressed spring. Using a meter stick, the students were able to estimate the highest point of flight of the projectile. By comparing the theoretical PEs with the observed PEg, the students were able to conclude that energy appeared to be conserved, with small differences due to friction and measurement errors.

PE_s to KE: Students examining this conversion used a spring and plunger mechanism to "fire" an air cart down an air track. The spring constant was carefully measured, as was the compression distance. A

photogate was used to determine the speed of the air cart. Shortly after the students started the project, they began to draw the conclusion that energy was not conserved in this particular PEs-to-KE conversion. Discussions with other groups (which were encouraged) led the students to become skeptical of their own results. When other groups began to find that energy was being conserved in their situations, this group took a critical look at their experimental setup and came to a realization that not all energy was being transferred from the spring to the air cart. They concluded that a massive plunger that transferred energy from the spring to the air cart was still in the possession of energy after it recoiled. By carefully observing the recoiling plunger, the students were able to estimate the amount of energy remaining in the plunger. They concluded that energy was conserved to within the limits of observation.

KE to PE_g*:* This group decided to use a photogate to measure the speed of a pendulum bob as it passed through it lowest position, and then to determine the maximum height to which the pendulum bob rose by examining the maximum angle of the support string from the vertical. Conceivably the simplest of experiments, this group had a difficult time. The students worked out the theory in short order and quickly came up with a very large experimental error. They concluded from their observations that energy was not conserved to any significant degree. Cognizant of the fact that other groups were finding that energy is more or less conserved, one student in this group started looking carefully at the collected data and concluded that the rapidly moving pendulum bob could not possibly have taken 0.72 seconds to pass through the photogate. This time interval was being used to calculate the initial speed. Clearly, something was wrong. Once a miscalibration was discovered and corrected in the photogate's software setup file, the group was able to conclude that energy is indeed conserved in this situation, and to a very high degree.

KE to PE_s*:* In this remaining case the group chose to slide a bundle of metal bars down an inclined plane to see how much compression would be produced in a stiff spring at the end of the slide. The group members failed to realize that energy is dissipated through frictional forces, even though this concept had been addressed at some length in class prior to the beginning of the project. After coming to an understanding of the complications introduced by friction, they quickly redesigned their experiment to use a cart on an air track. The speed of the air cart was determined with the use of a photogate, and the compression of the spring was observed directly. They, too, concluded that energy appeared to be observed.

Since some research groups worked more quickly and efficiently than others, not everyone was involved in laboratory work throughout the allotted time. Faster groups took advantage of the available in-class time to prepare their project reports and get ready for their class presentations. Slower groups had to prepare their project reports and make plans for their presentation of class. Five days were originally allocated to in-class research. However, the students required nine days to conclude their research.

Informal Findings

Throughout the course of this experience, students were informally queried about how they felt aboutthe research projects as they were progressing. At the outset of this exercise some of the most academically talented students vocalized that they did not "like" the project. Other gifted students expressed that, for once in their lives, they were being academically challenged. When these students were asked, none of them admitted to ever having had such a non-directed laboratory experience in their educational careers! One outstanding student became somewhat despondent when the undirected approach proved to be more difficult than expected. He reported, "I don't like this; I'd rather be told what I have to know." By the end of the project, however, these students remarked favorably about the overall experience.

Some of the academically challenged students performed exceptionally well. One student who had shown little motivation throughout the first semester became fully engaged in the process and demonstrated enthusiasm, leadership, and creativity. Another of these students spontaneously called out “Physics is fun!” when she thought the instructor was out of ear shot.

Even though this non-directed laboratory approach was enjoyed by most of the students most of the time, there were moments when some students became disillusioned with the process. Some students felt lost and periodically complained to the instructor that the activity lacked direction. Other students wanted the teacher to “solve the problem” when they were having difficulties. Of course, the instructor refused to do more than offer a few probing questions. In two cases, groups had to start over when they discovered that their experimental designs were flawed. This resulted in a certain amount of consternation. At least one gifted student involved in redoing a project concluded that she didn’t seem to have the pluck to be an experimentalist.

Confronting the unknown is difficult work, especially for students who may never have done so before. Because these students were not accustomed to dealing with the problems of research, they needed breaks from the daily pressures of the exercise. The instructor therefore punctuated the lab work with discussions to address problems of mutual concern, examine scientific methodology, and deal with issues of professional ethics. In one case, a student suggested to the members of his research group that things would work out “better” if they faked the data. Fellow group members were repelled by the suggestion. This information was privately communicated to the course instructor who took part of the class period the following day to discuss professional ethics. These are teachable moments, and it is advisable to take advantage of the opportunity to do so.

Survey Results

A thirty-question survey was administered to all students at the end of the laboratory exercise in an effort to get a complete picture of student attitudes as they related to the non-directed research project. Student comments were generally positive. The students enjoyed learning about how science is performed. They enjoyed thinking creatively about possible solutions and being allowed to use a more “hands-on, minds-on” approach.

The students’ negative comments fell into two main groups. First, the students frequently indicated that they did not like the makeup of their mixed-ability groups. They rather would have determined their own research group makeup. A number of students reported a lack of cohesion among group members, leading to a mildly unpleasant experience for some.

The other group of negative comments concerned guidance. About one-third of the students felt more guidance was necessary during the experiment. These students indicated that when they encountered an impasse, the teacher should quickly assist. About one-half of the students felt that problems were effectively resolved with concurrent class discussions and the sharing of information between groups. These students also indicated that more background on the problem and independent experimentation would have been helpful.

What is more important, the survey showed that more than two-thirds of all students wanted the exercise to continue longer, and recommended that it be repeated next year. Approximately sixty percent of the students surveyed agreed or strongly agreed that the non-directed research project was effective in helping them learn physical principles and scientific procedures.

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Alternative Assessment

Many of the time-honored methods of evaluation had been utilized in the instructor's class prior to beginning this project: tests, quizzes, homework, and lab reports. Missing from this repertoire was assessment where students were evaluated on the basis of both conceptual and procedural knowledge in an authentic setting. The format of this project permitted a variety of alternative assessments:

- instructor evaluation of group laboratory work
- peer evaluation of group presentations
- peer evaluation of individual laboratory work
- instructor evaluation of project reports

The non-directed research project was assigned a worth of 50 points. Ten percent of the grade for this project came from the instructor's evaluation of group laboratory work; fifty percent came from peer evaluation of group presentations; twenty percent cam from peer evaluation of individual laboratory work; and twenty percent came from the instructor's evaluation of the project reports.

The instructor's evaluation of group lab work included subjective assessments of the following factors: independence in thought and action, creativity in approach to solving the problem, scientific attitude, determination and effort, and effective use of time.

Peer review of group presentations was highly structured. Students were given a list of questions to serve as the basis of evaluation. Questions such as, "Was the goal of the project made clear from the outset?" and "Was the working theory dealt with adequately?" and "Was the experimental procedure adequately described?" served as guidelines to evaluation. It should be noted that all students received a copy of the evaluation form several days prior to the presentations.

Peer review of individual contributions to the group's work was subjective in nature. Students were asked to rate their peers' contribution to the group effort on a scale of 0 to 10, with 0 representing no contribution and 10 representing outstanding contribution. Students were also asked to justify their rating by writing a brief explanation.

Lab reports were graded in a more or less traditional fashion by the course instructor, with points assigned for problem statement, theory, procedure, data collection and interpretation, error analysis, and conclusion.

Discussion

The value of cooperative learning is well known.[1-3] It might be argued that non-directed laboratory approaches such as the one described in this article require too much time and that students can be taught through expository means in a much quicker fashion. The authors' response is that students benefit disproportionately from the time they might have otherwise spent in a more conventional lab or lecture setting.

Learning in independent research is achieved by students doing science -- making observations, discussing findings, asking questions, forming hypotheses, experimenting, debating results, correcting errors. These types of activities align closely with the procedures described in Project 2061 as being essential for preparing scientifically literate students.[4] Students learn to do science when they work like scientists. Contrast this with reception learning where students are seen as passive receptacles to be filled with knowledge.

One might still argue that students won't learn enough content when using the inquiry-oriented approach. Lawson argues that more traditional expository approaches leave students with too much information that all too often is misunderstood and rarely retained.[5] He also points out that most standardized tests such as the Iowa Tests of Educational Development, the Scholastic Aptitude Tests, and the new ACT Test of Critical Thinking emphasize reasoning skills over content knowledge, and that students who have been taught using inquiry-oriented methods of instruction will outperform those who have been taught using content-centered pedagogy. He goes on to argue that students who have been taught using an inquiry-oriented approach will receive an education that focuses on the major themes of the discipline and will therefore receive a much broader understanding.

Though the non-directed laboratory approach may prove difficult and time consuming for inexperienced students, difficulties and frustrations can be overcome by giving helpful procedural hints. The choice of openness or structure for laboratory work will depend upon the level of the students' creative and critical thinking skills, and their past experiences with laboratory work. For more skilled students the authors highly recommend using a non-directed laboratory approach from time to time.

The authors are of the persuasion that a scientifically literate person will be able to apply the knowledge and procedures of science to the solution of everyday problems. A person who possesses great content knowledge but knows nothing of the procedures of science might have great difficulty in applying that knowledge. Such a person might be scientifically well informed, but not necessarily scientifically literate. A scientifically literate person will be one who is able to understand and apply the processes through which science functions. Non-directed laboratory activities have a role to play in teaching for scientific literacy.

The key issue raised by this discussion is the value of active, self-directed learning over passive, reception learning. The former approach is essential if growth in conceptual and procedural knowledge is to take place. The former approach is essential if students are going to become scientifically literate.

References:

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