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AUTHOR	Petrosino, Anthony J., Jr.
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ABSTRACT

This document examines how a unit on model rockets, designed to be a "hands-on" activity within the "Mission to Mars" curriculum that was implemented in the Nashville (Tennessee) area middle schools, has been used to investigate children's understanding of experimentation. A literature review explores some of the traditional constraints placed on children in the field of science education and describes the development of the model rocketry unit in the "Mission to Mars" curriculum. The study participants were 23 fifth- and sixth-grade students in a summer school classroom. Each student was interviewed individually regarding the objectives of the model rocket activity, especially building the winning model rocket design as opposed to a more comprehensive view of the purpose of the experiments. Additional questions addressed students' understanding of comparisons. Over the course of the interviews, many students seem to have understood the importance of comparison, and a majority were able to see their conclusions applying not only to their own model rocket design but to rockets in general. By the final interview, 15 of 16 students stated that studying models made of cardboard and plastic were relevant for studying real rockets, and almost the entire class was able to present realistic modifications to the original experiment. Figures on student interview data are attached as well as a copy of the request for design plans from the Office of the Training Director. (Contains 35 references.) (ND)

Authentic Experience within Investigative Activities: The Role of Reflection in the Learning Environment

Anthony J. Petrosino, Jr.
Cognition and Technology Group at Vanderbilt
Learning Technology Center

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Authentic Experience within Investigative Activities: The Role of Reflection in the Learning Environment

Anthony J. Petrosino[1]
The Learning Technology Center
Vanderbilt University

It should seem rather self-evident that performing laboratory experiments in cookbook fashion, without understanding the underlying substantive and methodological principles involved, confers precious little meaningful understanding, and that many students studying mathematics and science find it relatively simple to discover correct answers to problems without really understanding what they are doing. (Ausbel, 1963; p. 291)

Students need to become more systematic and sophisticated in conducting their investigations, some of which may last for weeks or more. That means closing in on an understanding of what constitutes a good experiment. The concept of controlling variables is straightforward but achieving it in practice is difficult. Students can make some headway, however, by participating in enough experimental investigations and explicitly discussing how explaination relates to experimental design. (AAAS, 1993; p. 12)

This standard (inquiry) should not be interpreted as advocating a "scientific method." The conceptual and procedural abilities suggest a logical progression, but they do not imply a rigid approach to scientific inquiry. On the contrary, they imply a co-development of the skills of students acquiring science knowledge, in using high-level reasoning, in applying their existing understanding of scientific ideas, and in communicating scientific information. This standard cannot be met by having the students memorize the abilities and understandings.It can be met only when students engage in active inquires. (NRC, 1996; p. 144-145)

Introduction

A dominent theme of recent educational standards has been the incorporation of teaching for inquiry. This has been particulary true in the area of science education (Duschl, 1996). From the cautions of Ausbel (1963) who realized and accepted the importance of "discovery" but cautioned about it being used as a panacea to current calls for the inclusion of higher order thinking and real experimentation in children's science activities by the American Association for the Advancement of Science (1993) and the National Research Council (1996), the way in which students "do" science in the classroom has been of significant importance. However, successful

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[1] Paper to be presented at Session 16.41 of the American Educational Research Association. Chicago IL, March 24-28, 1997. Correspondence: Anthony Petrosino, Box 45, Peabody College, Vanderbilt University, Nashville, TN 37203. (615) 343-1701 E-mail: Petrosa@ctrvax.vanderbilt.edu

implementation of inquiry in the classroom has not been easily achieved (Welch 1979; Kyle, 1980) and continues to be a difficult goal to achieve (AAAS, 1993; NAS, 1996). While elementary and middle schools are in the process of attempting to implement the Council's recommendations for the expansion of inquiry based or hands-on approaches to science instruction, the objectives of authentic experimentation are infrequently pursued (Schauble et al, 1995). Instead of extended student investigation of phenomena and events of meaning, students in traditional hands-on programs too often engage in short, unrelated activities that compromise higher order thinking in exchange for the manipulation of science materials and equipment.

Scientific reasoning in the form of experimentation has traditionally been placed out of the realm of elementary and middle school students for purposes primarily concerned with developmental constraints (Metz, 1995). Fortunately, as these original presumptions upon developmental constraints have been reformulated, there is a reconceptualization underway as to the reasoning capabilities of children as it pertains to scientific understanding. This reconceptualiztion coupled with modern learning theory which focuses on the students' authentic participation in the practice of science has implications for how we conceptualize student understanding of scientific thinking as well as how we reformulate instructional activities to allow students to exceed the limitations of past practice.

Application and Theory in the Learning Environment

Glaser (1994) discusses the interaction between theory and application in science stating that it is first, often bidirectional and second, that it does not necessarily move as often portrayed from pure science to application. He proceeds to explain five different kinds of interactions between theory and application. Specifically, (1) the direct application of theory to practice, (2) the influence of practical application on experimental and theoritical work, (3) the lack of relevance much of experimental research for understanding complex performance, (4) the setting aside of learning theory until cognitive outcomes of learning were better analyzed and (5) the mutual interaction of theory and application so that one could inform the other.

He further continues that in the 1990's the field of education research is changing. Well known scientists are spending less time to traditional experiments and are instead in the process of design development of educational environemnts in which students can acquire knowledge and skills for thinking and learning (Bruer, 1993). This era is characterized by two foci. First, there is less emphasis on building theory from laboratory tasks and more on authentic human performance in educational and social contexts. Second, there is increased emphasis being placed on the bidirectional relationship between science and application. Work on these educational settings is redirecting the field (Glaser, 1994) as design experiments (Brown, 1992) are leading to progress in the understanding of learning and instruction.

The current work seeks to explain the evolution of how a unit on model rockets originally designed to be a "hands-on" activity within the Mission to Mars curriculum (Petrosino, 1995; see also Figure 1) has been used to attempt to come to an understanding of children's understanding of experimentation. I will first describe some traditional constraints placed on children in the field of science education. I will then give a brief description of the development of the model rocketry unit in the Mission to Mars curriculum. Finally, I will present some initial results of a study conducted last year in which reflection and revision was incorporated into the Mission to Mars unit. The results of which may eventually have implications for understanding how to better structure investigative activities for students.

Experimentation in the Science Classroom

A close inspection reveals that approaches to experimentation in science instruction are often fragmented and artificial, focusing on separate and isolated skills. Consequentially, investigative activities in the science classroom are often concentrated upon a series of unrelated activities separate from any meaningful inquiry or context. Examples of such activities include data recording, measurement, estimation or lab reports. The same issues of fragmentation have plagued psychological studies on experimentation as well. Often, for methodological issues concerning experimental control of their own studies, researchers have compartmentalized experimentation into isolated abilities. For example, studies have been conducted on data interpretation (Shaklee & Mims, 1981), design of experiments (Tschirgi, 1980), and data recording and keeping (Siegler, 1981). While these studies have provided essential knowledge, there is growing evidence that these components do not function autonomously (Klahr & Dunbar, 1988).

Past Practice

A widespread conjecture is that young children are not equipped with the facilities to be experimentalists. The genesis of this supposition can be traced to the developmental assumptions that the logic of experimentation is not fully grasped until the adolescent years (Inhelder and Piaget, 1955/1958). From this assumption, the postponement of scientific inquiry which incorporates the planning and execution of experiments as well as the resulting inferences drawn from those experiments have been defended for decades.

According to Metz (1995), the assumption that young children are not capable of taking part in scientific experimentation can be traced to the predominant interpretation of Piagetian theory which hypothezied constraints on what it is that children could be expected to learn and understand. A simplistic interpretation of Piagetian theory, like that which influenced the science education reform movement of the 1960's (Brown, Campione, Metz, Ash, in press), led to continually underestimating the young students capabilities. What implications this had on the science curriculum will be discussed shortly. For now, we will look at specific studies documenting or disconfirming children's ability to experiment.

Apparent Weaknesses of Children's Ability to Experiment

The research literature has identified a number of weaknesses in children's scientific inquiry. For instance, Dunbar and Klahr (1989) as well as Schauble and Glaser (1990), found that the design of children's experiments are often planned in such a way that it is impossible to reach any reliable conclusion. Furthermore, when experiments are performed, students often keep inaccurate records of the results (Schauble, 1990; Siegler and Liebert, 1975). Students also tend to ignore evidence that disconfirms (Kuhn, et al. 1988). On a related note, the evidence that students do consider is more often than not insufficient to support an hypothesis (Dunbar and Klahr, 1989; Kuhn, Amsel, and O'Loughlin, 1988).In addition, children's goal structures may resemble an engineering model (design driven) more than that of a science model which is hypothesis driven (Schauble, Klopfer, and Raghavan, 1991).

Opportunities for Encouragement in Children's Ability to Experiment

Other research has indicated perhaps a more positive or optimistic view of children's scientific inquiry. For instance, there seems to be little difference between experiments run by adults or children in a LOGO computer based environment (Dunbar & Klahr, 1989). Furthermore, Klahr, Fay and Dunbar (1993) indicate that students as early as the sixth grade were able to differentiate theory from evidence. Most encouraging has been studies which give an indication that children's ability to engage in scientific inquiry improves simply as a result of structures allowing for the opportunity to engage in self-regulated exploration. For instance, concerning the adequacy of evidence underlying inference, Kuhn, Schauble and Garcia-Mila, 1992) reported substantial improvement. Additionally, Schauble, Klopfer and Raghavan (1992) reported that data-base inferences improved over a series of sessions in which students took part in self-regulated exploration.

As Siegler points out (1991) adults as well as children often have difficulty performing valid experiments, interpreting data correctly, and clinging to existing theories even when evidence seems to contradict their assumptions. Even professional scientists make similar errors under some circumstances (Greenwald, Pratkanis, Lieppe, and Baumgardner, 1986). As it seems, identifying cause and effects through experimentation and data analysis remains a challenge throughout our lifetimes. Moreover, the perception of science as a hypothetico-deductive process is inconsistent with recent descriptions of the way in which scientists actually work (Dunbar & Klahr, 1989).

Implications of Perceived Developmental Constraints on Experimentation

This brief analysis along with more elegant and detailed descriptions by Metz (1995) and Brown et al. (in press) suggest that any developmental rationale for children's science instruction to focus exclusively upon the directly perceivable and concrete, as well as the processes of observation and classification while postponing more abstract concepts and investigations until later years is ill founded. How this is actually realized in the typical science instruction follows.

A simplified view of science education for the young high;ights two major activities. One activity consists of textbook instruction (Yeager, 1995) which is similar to reading about science (see Duschl, 1991 discussion on science as a process of justifying knowledge). Brown et al. (in press) points out four major drawbacks to traditional textbooks. First, there is an assumed developmental sequence. Second, the texts are often narrative rather than expository making it difficult for children to distinguish fact from fiction. Third, there is a lack of coherent themes or underlying principles (see discussion on deep principles, Brown et al., 1996). And last, causal explanations are omitted causing a concentration on facts rather than understanding. The second activity involves children in hands-on activities through which students apparently seem to do science. Although, as Schauble et al. (1995) demonstrated rather convincingly in a study in which sixth grade students were probed for their understanding of the objectives and procedures in experimentation after completing a curriculum which consisted of over 100 hands-on experiments, little understanding of scientific reasoning could be ascertained after detailed interviews.

A Road to Simplification With Authenticity

Clearly, science instruction needs to be simplified to some aspect in the context of young children's instruction. Encouragingly, alternative routes of simplification exist. As Metz (1995) illustrates, the finding that children's understanding may be more in line with that of designers and engineers than pure scientists (Schauble, Klopfer, & Raghavan, 1991) suggests that we investigate this as a possible way of framing science instruction. Brown, Collins, and Duguid (1989) have stated that authentic activity is vital for learners for it is the only way for them to gain access to engage at a level in which thay can act "meaningfully and purposefully". Brown et al. (1993) along with Lamon et al. (1996) have relied on distributed expertise to simplify the task of scientific inquiry for the individual while maintaining authentic activity for the classroom particiapants. What is unique across these programs is the route of simplification through contextualization and the authentic participation and practice of tools for science inquiry.

Development of the Model Rocketry Consequential Task in the Mission to Mars curriculum

The Mission to Mars unit has evolved in the last five years from an experimental 7 minute NASA funded video designed to assist and research children's problem generation to a 12 week McDonnell Foundation funded problem-based curriculum implemented in five Nashville area middle schools employing investigative activities, computer resources and a community of learners model of classroom interaction.

Petrosino and his colleagues (see Barron, Schwartz, Vye, Moore, Petrosino, Zech, Bransford, & CTGV; submitted) have worked in a number of sites in Nashville on a "Mission to Mars" curriculum that involves a component where students build and launch model rockets (Lamon, et al., 1996; Petrosino, 1995). Thousands of classrooms throughout the country engage in similar types of activities. In the Nashville sites, the opportunities to build and launch rockets have been extremely popular for students, teachers and their parents. Launchings frequently attract press attention with footage shown on local news programs. There are many reasons to proclaim such projects a success.

However, what do students actually learn from their experiences? After a couple of implementations, it was obvious that students learned very little from simply making and launching their rockets, and that it was possible to deepen their understanding without dampening their enthusiasm. For example, one thing students could learn is information about experimentation and measurement, so the rocketry project was modified to include these elements. This was accomplished by requesting students to submit design plans (see Appendix 1) for making a rocket-kit that would be used by many classes. The "Request for Design Plans" included the following specifications:

> *We are specifically interested in 3 questions. First, will our rockets go higher if we sand and paint them or leave them unfinished? While it would be much cheaper for us not to paint and sand our rockets, we want to maximize the height our rockets reach. Second, will the number of fins have any effect on the height of the rockets; primarily 3 vs. 4 fins? Again, there are economic considerations involved. Third, does the type of nose cone have an effect on the height of the model rocket? We have rounded and pointed cones.*

Compared to students from the previous years, these inquiry goals led students to reflect on the results from each rocket launch (see Figure 2), to notice features they had otherwise overlooked (e.g., the existence of large discrepancies in estimates of each rocket's height), and to debate what features should be experimentally manipulated in the subsequent rocket trial (see Figure 3). A benefit that stood out for one classroom teacher was the students' increased ability to generate their own questions to guide their inquiry. "That was one thing I was very excited about: that they didn't have answers to all their questions; but they had better questions. I was impressed to see that, and felt glad to be a part of that process." Evidently, providing the students with the learning-appropriate goal of optimizing rocket flight led students to consider issues they would have otherwise overlooked.

Interviews with students also revealed that they were able to articulate these more complicated design goals and that they had learned a great deal about issues of measurement as they attempted to carry out the “Request for Design Plans”. Consider the following excerpt from an interview with a student who had participated in the inquiry based condition:

> Q: So, why are you doing the model rocket activity?
> *We were doing it for NASA* [see Appendix 1] *and they asked us to see which rocket or which kind of rocket we could build to go in a straight path. We had to build the rocket and see which will go higher, the one with four fins or the one with three fins. Should it be painted or not painted. Should the nose come be rounded or pointed.*
>
> Q. How would you measure it?
> *You would get 150 meters away from the object. You set the finder of the altimeter to zero. Once the rocket launches you wait until it gets to its highest point and shoot and let go of the trigger. You then bring the altimeter slowly down and get an accurate number for the height* (see Figure 4 for a typical student’s graphical depiction of launch).

In contrast, a typical response from a student in the more traditional comparison condition, when asked about the purpose of the activity was: “You know, to build them and see how high they will go.” In response to the question about measurement, a common response was: “You know, look at it go up and see how high it goes”.

In the next section, we will examine what actually happened when the incorporation of reflection and revision was used within the model rocket activity.

Reflection and Revision was incorporated into the Mission to Mars unit

School

The setting for this teaching experiment was a fifth/sixth grade summer school classroom in a low income neighborhood of a Southeast metropolitan city. The school is located next to a number of federally subsidized housing projects. The socioeconomic status

(SES) of the students ranges from poverty level to lower middle class (Secules, Swink, Keeton, & Millican; 1995). The student population characteristics of the school during the academic year is 53.4% Africian-American, 40.9% Caucasian, 5.3% Asian-American, and 0.3% Hispanic (Miller, 1995). During summer school, the school population characteristics were skewed toward Africian-American students which made up 71% of the class. Because of the relatively large physical size of the classroom, there was a computer area as well as a desk area. The computers were arranged in a horseshoe with the open end facing the desk area. The desks were arranged in groups of 4 with two desks facing each other and perpendicular to the main classroom blackboard. Desks were moved around freely between the start and end of each day to accommodate any one of many activities the teacher deemed appropriate.

Teacher

The classroom teacher was actively involved in the teaching experiment. He taught all lessons during the intervention, was integrally involved in all aspects of the teaching experiment including teaching, reflecting, and planning the daily lessons. He was an experienced Schools For Thought (Lamon et. al, 1995) teacher, highly regarded among the project directors for his abilities and had four years of teaching experience at the time of the study.

Students

Participants in the study were 23 fifth and sixth grade students from a collaborating classroom. Each student was enrolled in summer school and was part of the SFT program for the entire eight weeks of summer school. Student enrollment in summer school indicates that the child has not passed two of the following subjects during the academic year: Math, Communication Skills, Science/Health, or Social Studies. The criterion for participation was simply enrollment in summer school and the return of a parent permission sheet within the duration of the study. The sample consisted of 8 boys and 15 girls (mean age at conclusion of the study =11.91 years, standard deviation was .839). Approximately 82% of the participants were Africian American with the remaining students being Caucasian (9%) and Asian (9%). Children in this summer school classroom came from a number of public grammar schools throughout Nashville. The vast majority (90%) of students were from lower-income families.

Materials:

Model Rockets

For the investigative activity, students partially constructed model rockets from kits. The rocket kit was a product of Estes Industries and the model was known as The Big Bertha™. The rockets measured 24 inches in length with a diameter of 1.637 inches and a weight of 2.2 ounces. The Big Bertha™ model was chosen for a number of reasons including its ease of handling, prior success with similar aged students (Petrosino, 1995) and fundamentally sound and durable construction characteristics. The model is easy to paint, and has changeable nose cones and fins making modification a fairly simple process. The flexibility of modification to the initial design of the rockets were a crucial consideration in the selection of The Big Bertha™ model.

Procedure

Each student was interviewed individually by the author. The interviews included more questions than the replication study and lasted a little longer than the baseline interview (20 minutes as compared to 15 minutes). This is accounted for since the model rocket activity lasted over a series of weeks and investigated concepts in considerable depth.

Coding

The coding scheme for these interviews were taken from that developed by Schauble et. al (1995). Two experimenters used 3 of the transcribed interviews to mutually validate the coding scheme. Twenty of the remaining forty-five interviews (44%) were than scored. Since several of the children's conceptions shifted during the interview (indeed, this was part of the intervention), only initial responses were scored for data analysis. The score awarded on any one issue was the highest score received for the first reply addressing that issue. Interrater reliability was 94.4%, and differences were resolved by discussion.

The interview included questions which encouraged students to reconstruct the goals and procedures of the experiment. In addition, other questions were asked which encouraged students to discuss in some detail aspects of the experimental design and interpretation of the results.An additional question was incorporated in order to have students address a problem not explicitly poised during the original model rocket activity.

Furthermore, one question asked students whether performing experiments with model rockets could provide any information about real rockets. It was known from previous research (Schauble et al.; 1995) that young students have substantial difficulty in comprehending the representational nature of investigative or experimental activities. Response modes varied; a majority of the questions called for verbal responses but others required the children to choose among presented items (most notably, the various configurations of model rockets), draw pictures, or discuss their own work undertaken in class (i.e. launch reports). This approcah was taken in order to create more authentic assessments for students (Barron et al, submitted; Stiggens, 1995), as well as provide realistic and alternative ways of approcahing student understanding (White & Gunstone, 1992) as well as provide useful information for the teachers' use throughout the study.

Goals of Experimentation

The first two questions were used to understand the children's developing understanding of the objectives of the model rocket activity. Of special interest was the extent to which students would focus on building the winning model rocket design as opposed to a more comprehensive articulation that the purpose of the experiments were to find out how to optimize height given certain constraints. The classroom teacher and researcher specifically were determined to underemphasize the competitive nature of the activity and attempted to instill a more classroom oriented ethos. Following from a distinction first made by Dewey (1913) and later by Schauble et al. (1995), the researcher and teacher were aware of a distinction between working for success versus working toward generalizable understanding.

Q1: Do you remember before the holiday that your class was working on a model rocket activity? Can you tell me what it was about?

Interview I

Upon the first interview, students were unclear as to what the model rocket activity was about. In part, the students were not yet distinguishing the entire Mission to Mars unit from the model rocket activity. This is further supported by the fact that 62.5% of the students (10 of 16) gave answers falling into the category of "other" such as "to go to Mars" or "to find out what we need to know about landing on Mars." 19% of the students (3 of 16) referred to the actual construction of the model rockets and 19% of the students (3 of 16) indicated "finding out which rocket went highest."

Interview II

During the second interview, 37.5% of the students (6 of 16) stated that the goal of the activity was to see which model rocket went the highest. But there was also specific mention of the letter from the NASA Funding Agency which made it quite clear that the students were not in competition with each other but were addressing the specifics of the original proposal letter. Five students (31.3%) still gave vague answers or referred to "going to Mars" indicating continued confusion over the separation of the Mars activity from the model rocketry unit. One student (6.3%) referred to specific procedures such as measuring the height of the rockets or making sketches (part of their lab reports) and four students (25%) referred again to the specific construction of the model rockets.

Interview III

During the third interview, 87.5% of the student responses (14 of 16) could now be clearly categorized as explicitly referencing the goal of the activity as finding out which type of model would reach the highest altitude. Many articulated the various design features of the models and also incorporated references to a "research project" and a final report. The remaining student focused on the procedures of the activity and gave a fairly detailed explaination of the launcing of the rockets and their measurement but little on the goals of the activity specifically.

Q2. What were we trying to find out with this activity?

The model rocket activity can be conceived as a hierarchy of superordinate and subordinate goals. The overarching goal is to present a model rocket design which will achieve maximum altitude. To achieve that goal, students needed to work on the subgoal of submitting a series of launch reports for each condition assigned or chosen (3 fins vs. 4 fins; rounded vs. pointed nose cone, and painted or unpainted fuselage). In turn, to achieve that goal, students needed to successfully build and test model rockets, including the incorporation of specific design features, sketching their launch path, recording air temperature and meteorological data as well as calculate the height of the model rocket. This data was then presented to the class an incorporated into a classroom database of launch results (launch heights vs design features). Within this complex activity, children's attention could have very easily been focused on the goal of constructing the most successful model rocket (Schauble et al., 1995; Tasker and Osborne, 1985) rather than emphasis the process of successful experimentation. This focus away from competition and toward a more general group ethos was not as difficult as imagined. While some may see the design competition feature of this activity necessary for the generation of strong and prolonged student engagement with the task, perhaps the obvious appeal of simply launching model rockets was enough to ensure sustained level of engagement by the students.

<-----INSERT FIGURE 5 ABOUT HERE------>

Interview I

This was a more directive form of the goal question. 31.3% of the students (5 of 16 students) focused on specific procedures of the activity such as "we launch the rocket then we measure how high it goes with the altometer." 56.3% (9 of 16 students) of the students focused on extraneous features of the Mission to Mars unit which had little or no bearing on the specific model rocket activity. One student (6.3%) referenced the NASA letter presented to them at the beginning of the model rocket activity. One student (6.3%) cited a rule summarizing what she had learned about designing good model rockets, for example "the three fins go higher than the four fins."

Interview II

During the second interview only 12.5% of the students (2 of 16 students) references extraneous features of the Mission to Mars unit. Six students (37.5%) focused on the procedures of the activity. Another 12.5% (2 of 16) referenced the objectives of the letter. The areas of most improvement occured in the number of students who said that the goal was to figure out which model rocket design would go the highest. In the first interview, only student responded in such a manner but by the second interview, 37.5% of the students (6 of 16) were now beginning to become aware of the goals of the experiment.

Interview III

By the third interview, only one student referenced either the extraneous features of the Mission to Mars unit. Three students (18.8%) now referenced the objectives of the NASA letter or cited a rule summarizing what they learned about model rockets. Roughly 44% (7 of 16 students) of the students interview by the end of the intervention now said the goal of the activity was to suggest the best model rocket design, "one that will go the highest". In addition, there was substantially more discussion by all the students by the third interview and with greater articulation.

The Importance of Comparison

It is common to consider experiments as having both positive and negative outcomes (Schauble, et al.; 1995). For instance, one may consider finding out which rocket will go higher, as a positive outcome and having to test a model rocket without as much altitude potential as a negative outcome. This is especially difficult since research indicates that children focus on positive outcomes. Negative outcomes (if one insists on using such terminology) however are particularly informative when one is seeking covariation or lack there of among variables and outcomes (Schauble et al., 1995). According to Schauble et al (1995), middle-school students seem to overlook negative outcomes in traditional classroom science lab activities. The following questions addressed students' understanding of comparison both in the sense of contrasting data of the independent variable or of negative and positive outcomes.

Q3. Why was it important to make more than one model rocket?

Interview I

For the first interview, 56.5% of the students (9 of 16 students) responded that there was no logical need for comparison. Their responses indicated the need for more than one model rested more with damage to the original than any coherent experimental need for comparison. One student (6.3%) emphasized the favorable outcome, "to see which model rocket goes the highest." Four students (25%) seemed to understand the value of comparison, stating that "we need to get better ideas for making good rockets." Two students (12.5%) gave no answers or indicated that they had no idea of an answer to the question.

<------INSERT FIGURE 6 ABOUT HERE------>

Interview II

By interview II the number of students who gave no logical need for comparison was reduced from 56.3% to 6% (1 of 16 students). Seven students (43.8%) emphasized the favorable outcomes scenario. Noteworthy of all, was that 50% of the students (8 of 16 students) gave indication that they were developing a fundamental understanding for the value of comparison. By the second interview, students were beginning to understand that their individual experiments were contributing to a classroom database that was assisting everyone in the decision process of evaluating what was the best overall rocket design for the purposes the proposal.

Interview III

By interview III ten students (62.5%), now indicated that they had an appreciation for the value of comparison. However, the raw number of students actually decreased reflecting the attrition that existed in the class from the beginning of the summer school session to its completion 8 weeks later. Only 3 students (18.8%) emphasized the favorable outcomes of the experiment and one student (6.3%) and two students respectively (12.5%) still presented no logical need for comparison or gave a response that would only be able to be classified as "other."

Q4. Why did your teacher put the model rockets up for everybody to see? Why did he think it may be helpful to look not only at your own model rocket, but also the model rockets that other students made?

Interview I

Three of the 16 children (18.8%) noted that the purpose of the demonstration was to compare "rockets that went high" with "rockets that didn't go high" or successful with unsuccessful designs. This is good evidence that they understood the value of comparing positive along with negative outcomes. An additional 2 (12.5%) mentioned comparison, but only among designs associated with positive outcomes (the model rockets with the highest altitude potential). Three students (18.8%) believed that the demonstration and video would help them a sense of how to build the model rockets or of rocket safety but said nothing about the relationship between design features and outcomes. It is worth keeping in mind that of all the replies mentioned so far to this question (8 students; or 50% of the class) provide some evidence that the children seemed to be aware of the value of comparison.

The remaining 8 students (50%) did not show such recognization for the value of comparison. They either focused on positive outcomes only ("so we could see which rocket would go the highest") or gave very vague answers ("to find out how to do it"). Therefore, over one-third of the class give little or no indication of the value in comparing model rocket designs for achieving maximum altitude.

Interview II

Five of the 16 children (31.3%) noted that the purpose of the demonstration was to compare successful with unsuccessful designs. No students mentioned designs associated with positive outcomes. Five students (31.3%) believed that the demonstration and video would help them a sense of how to build the model rockets or of rocket safety but said nothing about the relationship between design features and outcomes. Therefore, after the second interview over half the class (10 students; or 62.6% of the class) provide some evidence that the children seemed to be aware of the value of comparison. This was a slight reduction from the first interview.

The remaining 6 students (37.5%) did not show such recognization for the value of comparison. As in the first interview, they either focused on positive outcomes only ("so we could see which rocket would go the highest") or gave very vague answers ("to find out how to do it").

Interview III

Seven of the 16 children (43.8%) noted that the purpose of the demonstration was to compare "rockets that went high" with "rockets that didn't go high" or successful with unsuccessful designs. An additional 2 (12.5%) mentioned comparison, but only among designs associated with positive outcomes. Two students (12.5%) believed that the demonstration and video would help them a sense of how to build the model rockets or of rocket safety but said nothing about the relationship between design features and outcomes. It is worth keeping in mind that of all the replies mentioned so far to this question (11 students; or 69% of the class) provided some evidence that the children seemed to be aware of the value of comparison. Most of the children who dropped from the study were originally in this top group so while the raw number of children was not much different, there was movement on this question from Interview I to Interview III from the "none comparison" group to the "comparison" group. The remaining 5 students (31.3%) did not show such recognization for the value of comparison. These students were consistently in this group from the start of the study to the end.

In summary, a fair percentage of students seem to have understood the importance of comparison as they discussed the features of model rockets to attempt to determine which design features are casually related to maximum attainment of altitude. Over the course of the unit there was a definite shift in the percentage of students who had little sense of the value of comparison to the end where the value of comparison seems to have been more deeply appreciated and more at the students disposal.

Students seem to have made a basic transition in their conceptualism from the direct observation of specific events to making inferences concerning the relationships among model rocket features on the basis of their own acquired data that eventually became an object of reflection (e.g., nose cone design and altitude). In general, students appeared to be comfortable with reflecting about their own model rockets and the height they obtained, they also gave thought to the model rockets in the class that reached heights below or above what they obtained and drew conclusions from them. This occured since the teacher placed the results of the entire class on the blackboard for public display. This made it somewhat easier for the students to regard the model rockets of the entire class as a data set illustrating a pattern of information (this was done after each rocket launch and students get a copy in their notebooks as well). However, more complex relations between design features, such as additive relations (e.g., rounded nose cone and four fins) were impossible to perceive.

According to Schauble et al. (1995) teachers rarely overtly discuss the meaning of data patterns, but assume that the meaning of the data is obvious. However, with the teacher acting as an agent for the development of meaningful data interpretation, the students were able to transition from generating relations between spontaneous concepts (acquired through everyday experience) to more appropriate scientific concepts (i.e. those learned in school) presented and learned as part of a system of relationships (Vygotsky, 1986).

According to Howe (1996), Vygotsky suggested that scientific concepts take on little meaning for the child unless grounded in rich personal experience. Spontaneous concepts tend to remain local and situational until they achieve the power of scientific concepts. From this perspective, the children's experience and engagement with the model rocket activity stimulated spontaneous concepts that were an important foundation for their eventual appreciation and developing understanding of more abstract ideas about data patterns and relations among variables. In the same sense, coming to understand the scientific concepts allowed the students' to develop knowledge with more power and applicability.

For understanding and assimilation to occur, the scientific concept (in this case, experimentation and aerodynamics) must be applied to concrete examples (specific rocket launches). In addition, the child must think about what this means in association with their prior experiences. In this manner, the child moves toward a more coherent understanding as they move back and forth between everyday experience and making it fit into a scientific conceptual system. In this manner (Howe, 1996), the goal was to assure that the concept learned in class would not remain a verbalism but would be applied to actual situations and phenomena encountered in their everyday lives (investigative activites outside the classroom).

Over the course of the interviews, the students progressed to a point that a majority of them were able to see their conclusions applying not only to their own model rocket design, but to model rockets in general and perhaps eventually to a more general class of ballistic objects.

In a similar fashion, it has been noted that students often fail to realize that the field of science values an active search for information (Benchmarks, 1993; Standards, 1995). In most traditional school settings, it is often difficult to have students pay attention and reflect about the ideas and work of others. This is especially true in school contexts where the teacher is often viewed as the only source of legitimate knowledge (Schauble et al., 1995). By having students post and reference the findings of their work in a public display, along with discussion of their theories and experimental observations, the classroom (with the assistance of the teacher) can become a place of public display for legitimate scientific findings (Lamon et al., 1996).

The Representational Nature of Experiments

In the weathering experiment at the beginning of the study, students had difficulty grasping the idea that components and activities in an experiment can be utilized to represent (as opposed to replicating) objects and physical processes in the world. At a fundamental level, an experiment is essentially a model of the world, but students often fail to comprehend the implications of this idea (that experiments are essentially a way of learning about the things the models are meant to resemble).

Q6. Did making rockets out of cardboard and plastic tell us anything about how to design real rockets?

As the students tested various design features of the model rockets, there was a fair amount of dissatisfaction about who got to test which rocket configuration. For instance, if the new feature was the addition of paint to the fuselage, students wanted to test that particular rocket. The unpainted fuselage would have gone untested had it not been for the teacher's use of a random drawing from a hat to decide who tested which model rocket.

<------INSERT FIGURE 7 ABOUT HERE------->

When asked directly, 75% of the students (12 of 16 students) upon the initial interview said that making rockets out of cardboard and plastic would tell us nothing about how to design real rockets. The students used many justifications for their responses usually adding such comments as "the model rockets are much smaller and lighter than real rockets" or "you can't put a person in a model rocket, so it wouldn't tell you anything." By the second interview, there was a surprising transformation occurring in the class as the responses nearly reversed.

This time, upon asking the students the same question, 87.5% (14 of 16 students) said that making rockets out of cardboard and plastic was relevant to the design of real rockets, usually adding the further explaination that making a model and testing it can tell you what kind of rocket to "suggest to NASA" (referring to the initial design letter).

By the final interview, 93.8% of the children in the study (15 of 16 students) stated that studying models made of cardboard and plastic were relevant for studying real rockets. Students did present some limitations and more articulation in their responses, saying such things as "it's good for studying how many fins to use or if you should paint it or not, but it's not good for all the electrical stuff that goes inside the real rockets." This is consistent with suggestions from Benchmarks for Science Literacy (1993): "As students develop beyond their natural play with models, they should begin to modify them and discuss their limitations. By testing their models and changing them as more information is acquired, they begin to understand how science works (p.268)."

As Schauble et al. (1995) suggest, the children's responses to this question suggest that it is vital for instruction to allow for the discussion of the relationships between the objects and procedures in an experiment. In traditional classes, this is most often done by the teacher. When the class is set up in a more inquiry orientated fashion, such discussions may arise in a number of ways including, public debates, presentations and written launch reports. In either case, it is imperative that the children come to understand what aspects of the real world the procedures and objects in an experiment represent and which they do not. Although teachers and other adults in an extended learning community may assume this information is understood by students, in actual classrooms, it often is not (Schauble et al., 1995).

Revising an Experiment to Explore an Additional Question

As Schauble (1990) explains, designing an informative experiment is more of a challenge than interpreting an experiment. Eventually, students need to venture beyond simply carrying out preassigned experiments and begin to pose their own questions that can be investigated. To determine how students would approach such a situation, they were asked how they might revise the model rocket experiment to investigate an additional question not originally presented. (n.b.: This question parallels the weathering question which asked students on how to investigate the effects of a large rainfall on weathering of pebbles in a stream.).

Q7. Suppose we wanted to find out if the kind of material makes a difference in the model rockets. that is, whether the model rocket is made of cardboard and plastic, like we used in class, or aluminum, or maybe something else. Can you tell me how we could change out experiment to find out?

Student response to this question was vastly superior to the parallel question from the "weathering" experiment and showed substantial developmental growth over the course of the interviews. During Interview I 12 of the 16 students (75%) gave either no response to the question or showed very little understanding. Three students (18.8%) noted that the shapes of the rockets should be held constant "the rockets should all be the same except for the one thing you want to find out.").

<-----INSERT FIGURE 8 ABOUT HERE------>

Upon the second interview, there was a dramatic movement toward understanding some design features of an experiment. At this time point, one student (6.3%) gave little or no response, three students (18.8%) gave an indication that the shape or size of the rocket should be held constant and 12 students (75%) suggested building model rockets out of different material and compare how high they go. By the final interview, 93.8% of the class (15 of 16 students) had reached the point where they could effectively suggest a way of changing the experiment to accommodate this additional question. In conclusion, almost the entire class was able to present realistic modifications to the original experiment, in contrast to only 15% on the similar erosion item in the weathering baseline interview.

These results are consistent with those of Schauble et al. (1995) and indicate that one way to have middle school students generate meaningful experiments may in attempting to modify the design of familiar experiments. Various proposals and modifications to experiments can and should be openly discussed and debated in the classroom. Furthermore, students should have to consider if the modification is useful and to perhaps even think about what the results might be and what that would indicate.

Conclusions

If authentic investigative activities are to be pursued as an instructional strategy, it is best to keep in mind the findings of Tschirgi (1980) in which it was found that students of this age are just acquiring a simple experimental strategy which can effectively handle only one variable at a time. In fact, by the end of the summer school session, students were frustrated at not having enough time to actually carry out there own experiments and requested their own model rocket material "so that I can experiment until school starts." Clearly, these findings and the findings indicate that middle school students have more aptitude for designing experiments than previously expected. Provided of course, that there is instructional opportunities, practice and feedback in scaffolding how to think about them.

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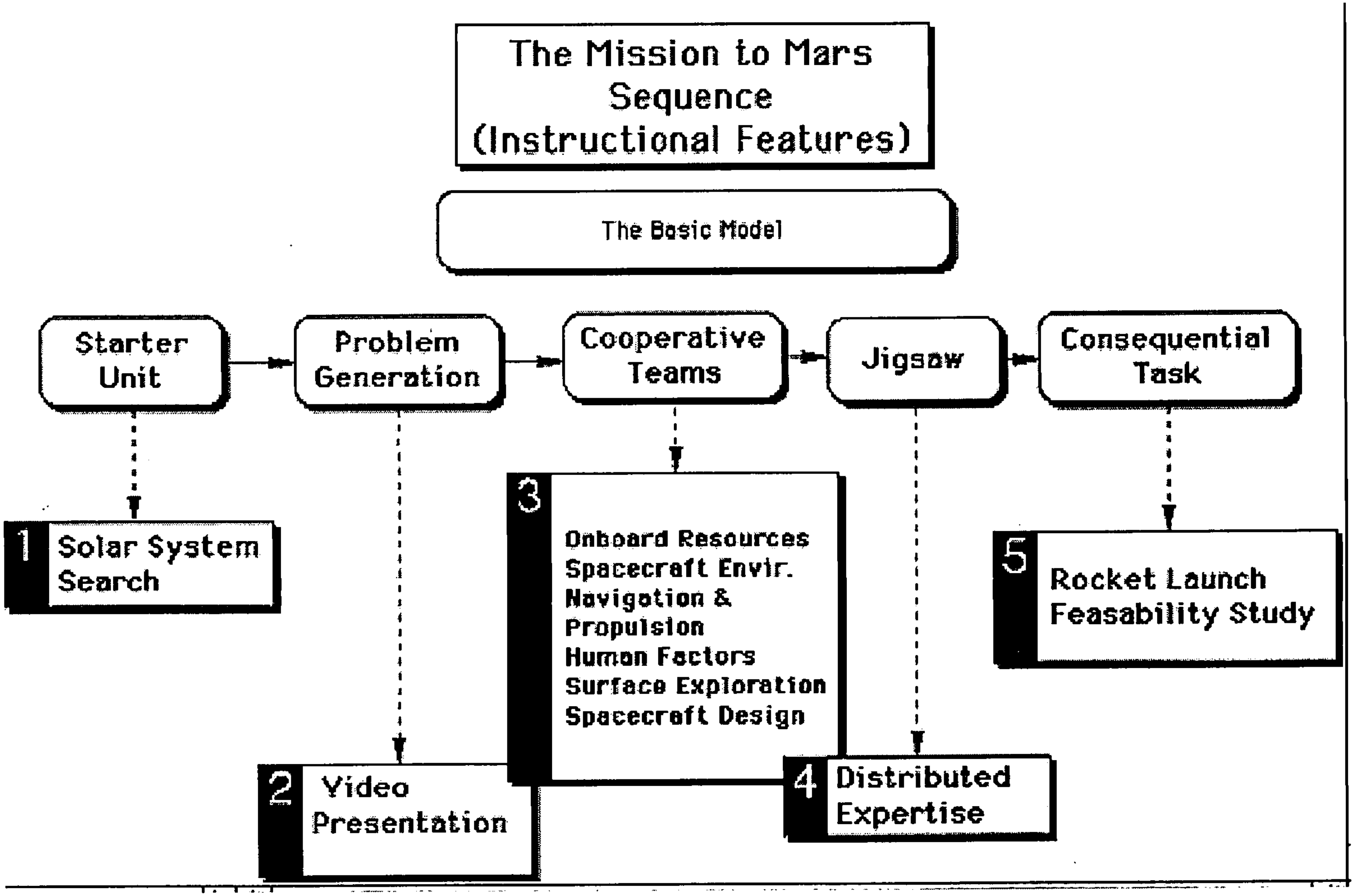
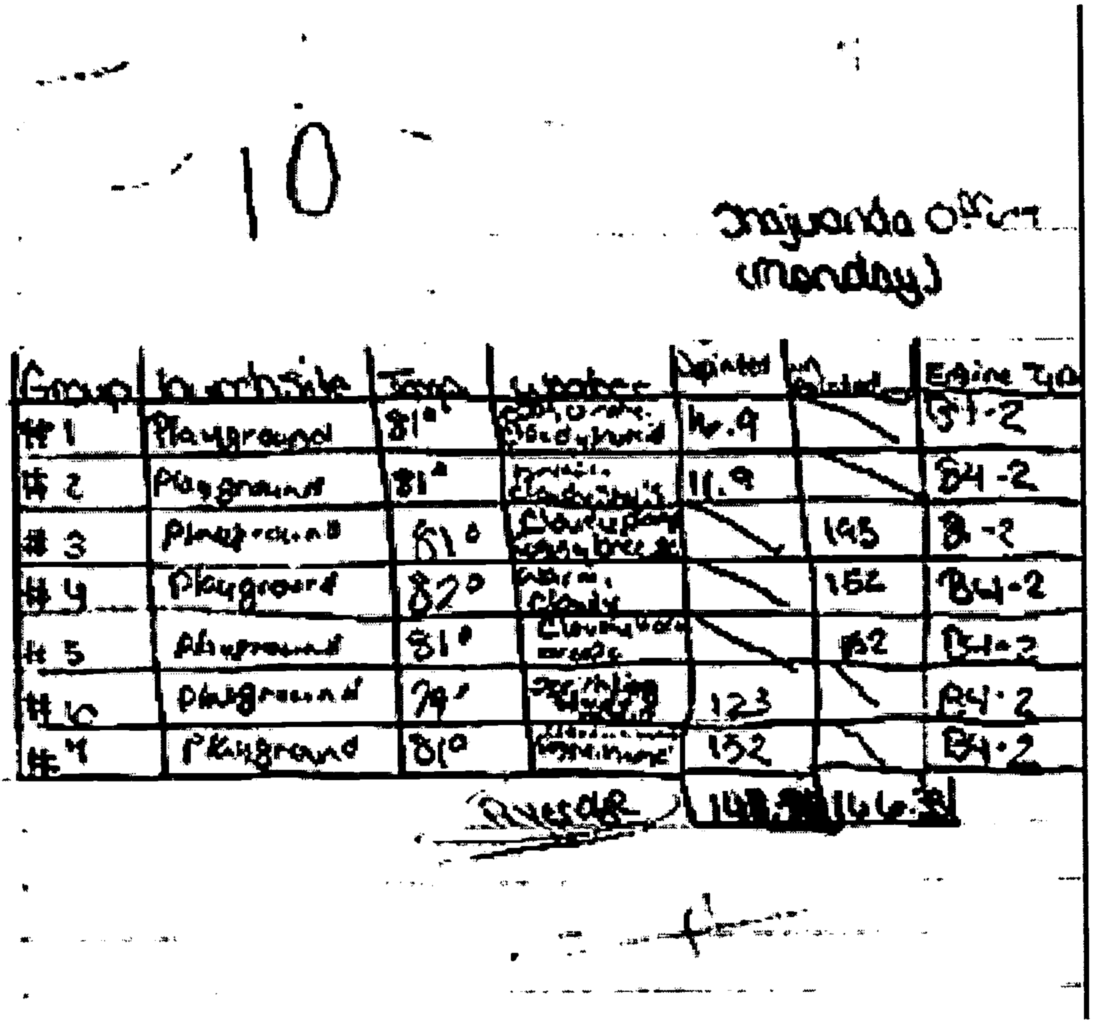
Figure 1



* Reprinted from Petrosino (1994)

Figure 2



10

[illegible]
(Monday)

Group	Launch Site	Temp	Weather	Painted	Unpainted	Engine Type
#1	Playground	81°	[illegible]	16.9		B4-2
#2	Playground	81°	[illegible]	11.9		B4-2
#3	Playground	81°	Cloudy [illegible] breeze		145	B-2
#4	Playground	82°	Warm, Cloudy		152	B4-2
#5	Playground	81°	Cloudy [illegible]		152	B4-2
#6	Playground	79°	[illegible]	123		B4-2
#7	Playground	81°	[illegible]	152		B4-2
			Average	14[illegible]	166.3[illegible]	

Figure 2 : While each group launched only 1 model rocket per condition (3 vs. 4 fins; rounded vs. Pointed nose cone; painted vs unpainted) data was accumulated and presented before the class. Each student keep track of the data forming many interesting tables to organize the information. Here, the student keeps track of the Group, the location of the launch, the weather conditions, the height and type of rocket (this table is from the Painted vs unpainted trial) and engine type.

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Figure 3

Shajuanda Offutt

5

Model Rocket Launch Report

Date: 7\11\96

Site:

Participants: Surfacing Explorers

Temperature: 73°

Weather Conditions (include wind, cloud conditions):
Cloudy, and slightly wind

Rocket Type: Big Bertha

Engine Type: B6-4 Engine

Height in meters & feet (please include any calculation):

first flight 99 meters Second flight meters 115-120

Almost 3 feet

Description of Flight:

first flight	second flight
It shot up almost perfactly Straight and ~~while~~ when the parachute come out the rocket came Back down	It went up farther than the ~~other~~ first one and it was the Best.

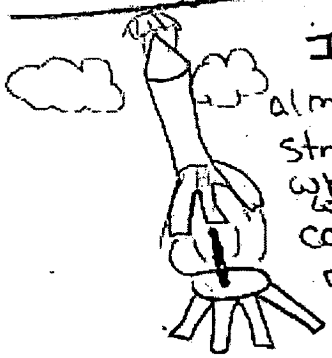


Figure 4

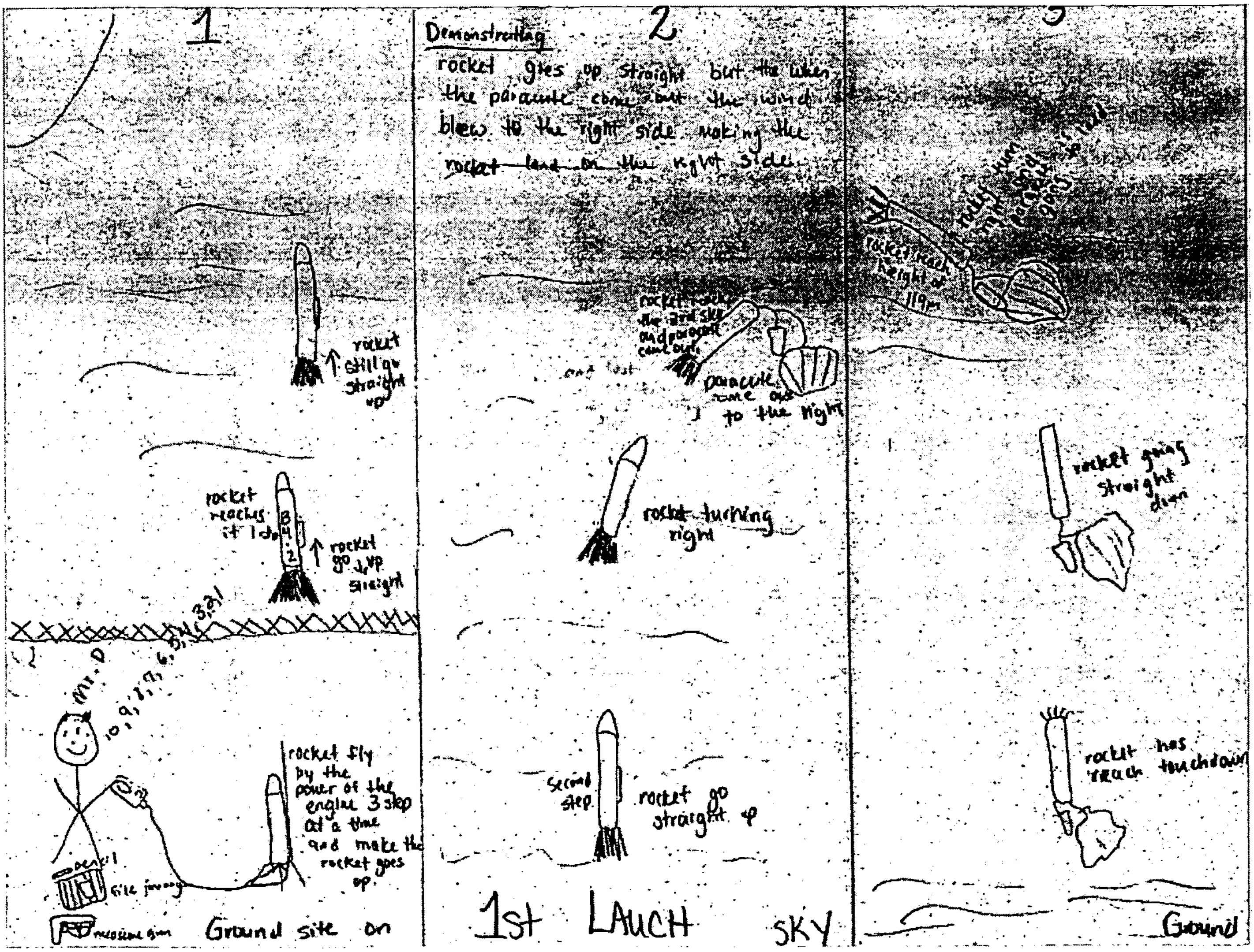
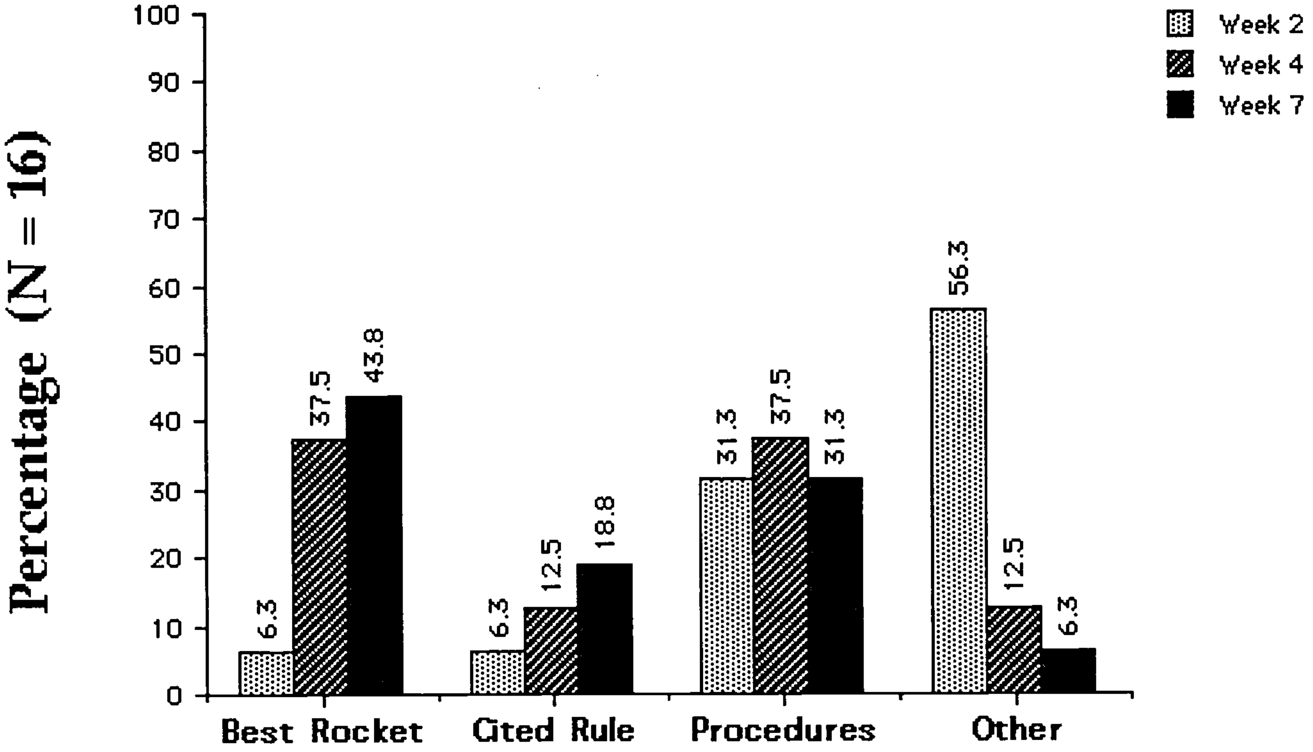


Figure 4: This is a student's drawing of the model rocket launch. The context of the NASA Design letter coupled with the submission of a design plan provided the initial motivation.

Figure 5

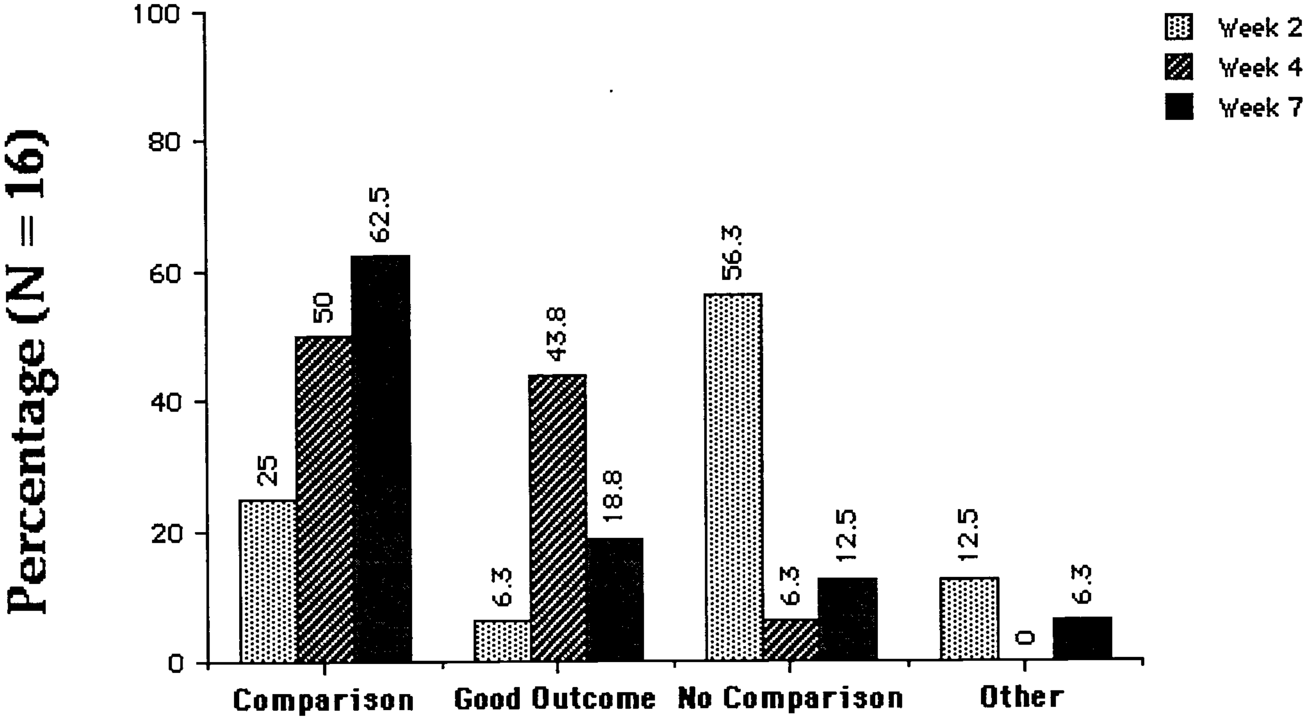


Q2. What Were We Trying To Find Out With This Activity?

Week2 — Week7: Significant $p < .05$

Figure 6

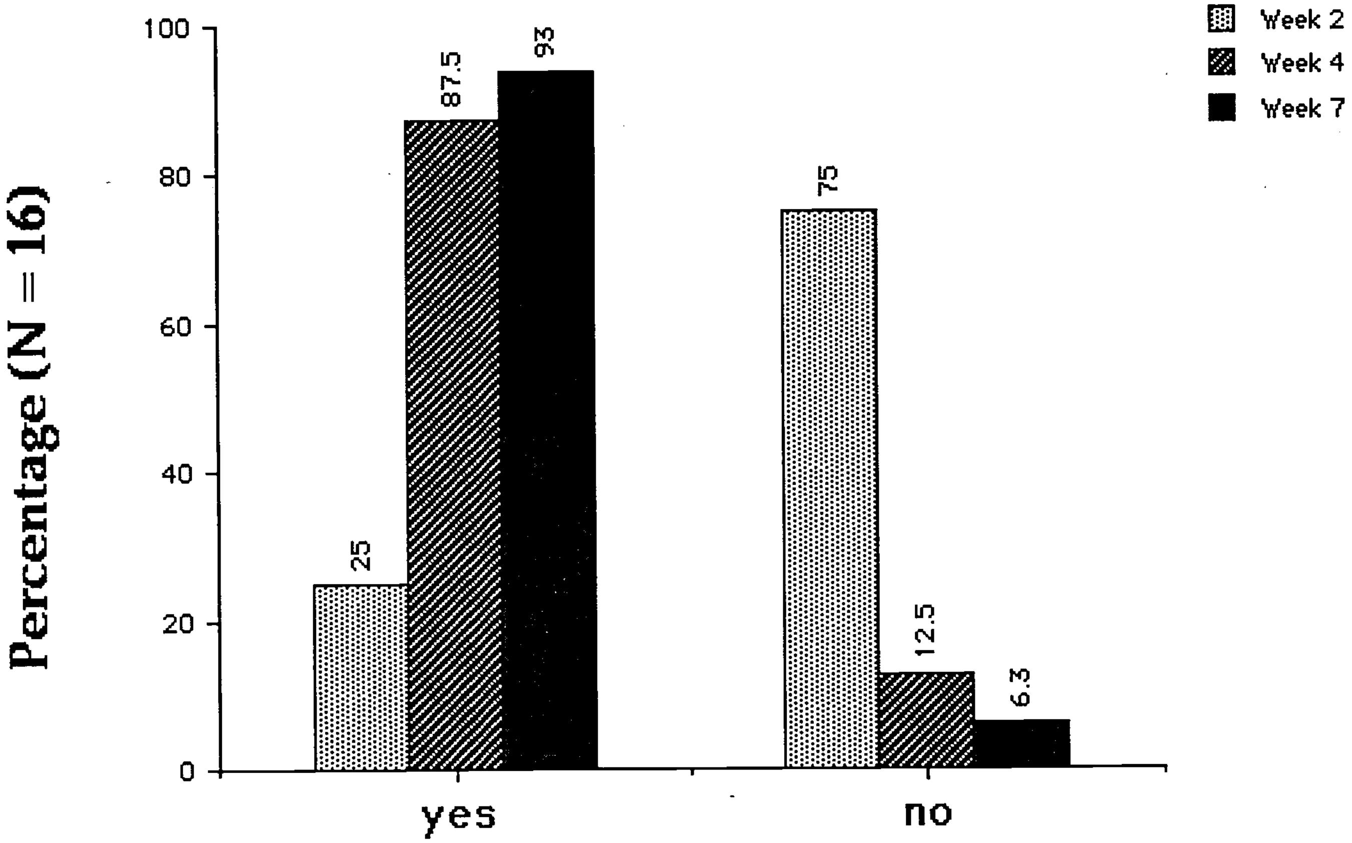
Q3. Is One Model Rocket Enough to Figure Out How to Make the Best Model Rocket?



Week2 — Week7: Significant $p < .05$

Figure 7

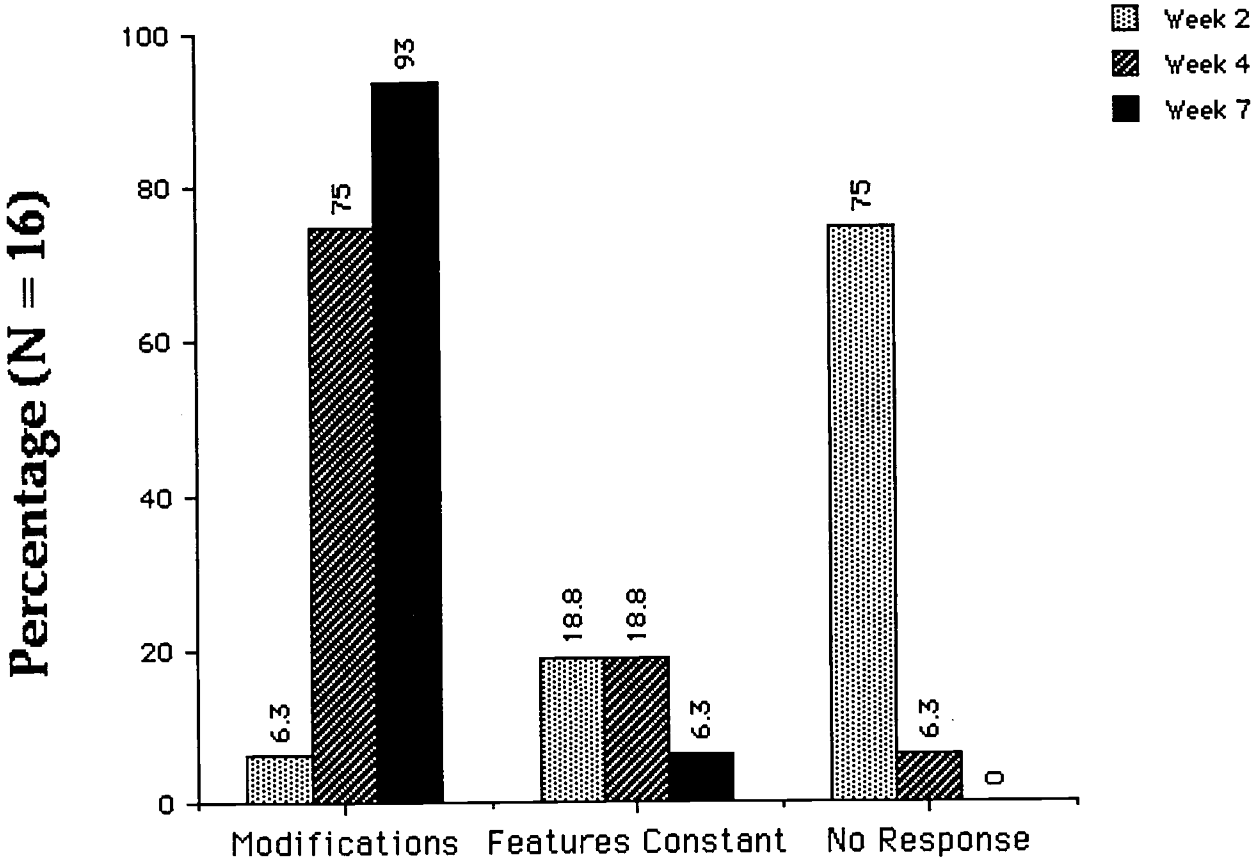
Q6. Did Making Rockets Out of Cardboard and Plastic Tell Us Anything About How to Design Real Rockets?



Week2 — Week4: Significant $p < .01$
Week2 — Week7: Significant $p < .01$

Figure 8

Q7. Can You Tell Me How We Can Change Our Experiment to Find Out if Other Materials Would Make a Difference?



Week2 — Week4: Significant $p < .01$

Week2 — Week7: Significant $p < .01$

National Aeronautics and Space Administration
Tennessee Space Grant Consortium
Department of Mechanical Engineering
Vanderbilt University

Office of Planning Director for Student Research— T. Petrosino
Phone: (615) 343-1701
e-mail: Petrosa@ctrvax.vanderbilt.edu

RE: Request for Design Plans

Dear Applicant:

The aim of this letter is to give you directions for a bid to our project. I am pleased to learn that you and your staff are interested in making rocket design plans. To help you with the making of your design plans, let me tell you how we plan to use the model rockets.

The Schools For Thought project hopes to use this model rocket activity as a key part of its program in other schools systems around the country. This activity has been used mostly by Nashville students only. We are very interested in a full account of your rocket design. You will find guidelines which we hope will help you in the making of a packet of information that you will submit at the end of this unit. Our goal here is twofold. First, we would like you to build rockets that will follow a straight path upward. Second, we want you to test three different features of the model rockets in order to scientifically prove which features will lead to the best overall rocket design.

The ability to carry out a research project is very important. The successful plan will be one that explains how a rocket should be designed so it flys straight while also being able to calculate (and measure) its height.

We are specifically interested in 3 questions. First, will our rockets go higher if we paint them and sand them or leave them unfinished? While it would be much cheaper for us not to paint and sand our rockets, we do want to maximize the height our rockets reach. Second, will the amount of fins have any effect on the height of the rockets. Primarily, 3 vs. 4 fins? Again, there are economic considerations involved. Third, does the type of nose cone have an effect on the height of the model rocket. We have rounded and pointed cones.

The packet of information you submit to The Review Board should contain the information and materials in the items listed below. Only complete packets will be considered. We want to hire the team that can design the best rocket plan. But the Review Board must have faith that the designers understand and can explain why a rocket will fly and reach a certain height. Without this explaination, the Review Board can not be certain the design model you give us work.

Design Packet Items

1. *A sketch of the model rocket.*
The sketch should be neat and have the height, distance around the body, and weight of the rocket labeled.

2. *Sketches of the rocket in flight, on its way up, at its maximum height and on its way to the ground.*

These three sketches should be side by side on the same piece of paper. Using arrows, science terms and the names of forces, label the sketches to explain the forces that act on the rocket in flight (from launch to touchdown).

These sketches are a very important part of the design packet. We want to hire the firm that understands and can best explain why rockets fly.

3. *A report of tests and results.*
Please list the tests, experiments, and investigations you performed. Then provide for The Board of Review a report of the results. For example, what is the height your model rocket will reach with a given engine thrust. Also, can you predict how high a rocket will reach with an engine you did not experiment with directly? Include in your packet any tables, graphs, or test design sketches you think will demonstrate you have thought through the problem carefully.

Good Luck!

Sincerely,

Tony Petrosino, Office of Planning Director for Student Research

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