Running head: PBS Science Achievement

Performance of Students in Project Based Science Classrooms on a National Measure of Science Achievement

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Abstract

Reform efforts in science education emphasize the importance of supporting student's construction of knowledge through inquiry. Project-based Science (PBS) is an ambitious approach to science instruction that addresses concerns of reformers. A sample of 142 10^{th} and 11^{th} grade students enrolled in a PBS program completed the 12^{th}-grade 1996 NAEP science test. When compared to subgroups identified by NAEP that most closely matched our student sample, white and middle class, PBS students outscored the national sample on 44% of NAEP test items. This study shows that students participating in a PBS curriculum were prepared for this type of testing. Educators should be encouraged to use inquiry-based approaches such as PBS to implement reform in their schools.

Performance of Students in Project Based Science Classrooms on a National Measure of Science Achievement

Introduction

Goals for improved student learning in science have lead reformers to establish standards for what students should know and be able to do, as well as what instructional methods should be utilized (AAAS, 1993; NRC, 1996). Key concepts and principles have been identified as targets for student learning. In addition, reformers recommend student centered, inquiry-based practices that encourage deep understanding of science embedded in the everyday world. A number of programs attempt to put these recommendations into action in classrooms (Minstrell & Van Zee, 2000). These new approaches to science instruction feature inquiry as essential for student learning (Krajcik, Blumenfeld, Marx, Bass, & Fredricks, 1998; Lunetta, 1998; Roth, 1995).

Parallel to efforts to improve instruction are attempts to assess what students know and are able to do in comparison to standards, using large-scale achievement testing (Michigan Department of Education, 2001; National Assessment Governing Board, 2000). Evidence indicates that students can attain deeper understanding of science content and processes when they engage in inquiry (e.g. Brown & Campione, 1994; Cognition and Technology Group at Vanderbilt, 1992; Metz, 1995). Yet, there are concerns that movement away from teacher disseminated coverage of content will limit the amount of science content to which students are exposed and given opportunities to learn (Hirsch, 1996). Some fear this will leave students at a disadvantage in large-scale achievement tests, which have become increasingly important indicators of science learning. What is needed is empirical evidence that links inquiry-based instruction with success on science achievement tests.

Project-based Science

Project-based Science (PBS) is one approach that addresses recommendations for science education by extensive use of student-directed scientific inquiry supported by technology and collaboration (Krajcik, Czerniak, & Berger, 1999; Ruopp, 1993a; Tinker, 1996b). The assumptions that provide the foundation for PBS are derived from a social constructivist perspective (Blumenfeld, Marx, Patrick, & Krajcik, 1996; Krajcik, Czerniak et al., 1999). It is assumed that students need to find solutions to real problems by asking and refining questions, designing and conducting investigations, gathering and analyzing information and data, making interpretations, drawing conclusions, and reporting findings. Collaboration and conversation is also considered essential. Collaboration involves students building shared understandings of ideas and of the nature of the discipline as they engage in discourse with their classmates and adults outside the classroom (Krajcik, Blumenfeld, Marx, & Soloway, 1999).

PBS pedagogy is built around five features that are used to design activities that: a) engage students in investigating a real life question or problem that drives activities and organizes concepts and principles; b) result in students developing a series of artifacts, or products, that address the question or problem; c) enable students to engage in investigations; d) involve students, teachers, and members of society in a community of inquiry as they collaborate about the problem; and e) promote students use of cognitive tools (Krajcik, Blumenfeld, Marx, & Soloway, 1994). Each of these features supports students in constructing understanding of important science concepts as they inquire into a real life problem.

In PBS the real life problem is framed as a question. The question - called the driving question - organizes and drives students' investigations (Krajcik et al., 1994; Tinker, 1996b). The driving question of a project is carefully selected to encompass real life problems that involve students in content outlined in district and state instructional objectives. The question is also chosen to be meaningful to students by being connected to their own lives or community, allowing them to take ownership of the question and to lead them to do investigations.

During investigations, students work within a community of learners. This collaboration includes peers, teachers, and members of the community who are all involved in sharing and debating ideas and constructing understanding. Technological tools are used where appropriate to enhance student understanding and are used repeatedly throughout the unit (Ruopp, 1993b; Tinker, 1996a). As students develop understanding they begin and continue to demonstrate their understanding through the building of artifacts. Artifacts can take multiple forms and are used as tools for assessments. Projects designed on PBS features also involve students in inquiry over time. Typically projects last around 8 weeks but can stretch to as long as 15 weeks.

One high school that had implemented PBS instruction in the classroom was the focus of this study. Using principles of PBS, project units were created to address integrated science content including biology, chemistry, and earth science concepts as needed to answer driving questions. Technology tools and collaboration among students and teachers were used extensively. Because project units replaced traditional science courses, 9th-11th grade students at this school participated in this form of inquiry-based science instruction exclusively. The performance of these students on a national achievement test would be one indicator of the potential for inquiry-based science to support students in developing science understanding.

National Assessment for Educational Progress

The National Assessment of Educational Progress (NAEP) developed by the National Center for Education Statistics, is a measurement tool used across the nation to assess student achievement in many subject areas including science. The NAEP science assessment is given to students in grades 4, 8 and 12, and results are reported at each grade and within various subgroups of the general population. NAEP results are also analyzed for trends across time. The most recent version of the NAEP available for public release at the time this research was conducted was the 1996 version.

The framework of the 1996 NAEP science test (O'Sullivan, Reese, & Mazzeo, 1997) includes three types of questions:

1) Multiple-choice questions that assess students' knowledge of important facts and concepts and that probe their analytical reasoning skills.
2) Constructed-response questions that explore students' abilities to explain, integrate, apply, reason about, plan, design, evaluate, and communicate scientific information.

3) Performance tasks that probe students' abilities to use materials to make observation, perform investigations, evaluate experimental results, and apply problem-solving skills.

The questions cover content in three major fields: earth science, physical science, and life science. The questions are also divided among components of knowing and doing science: conceptual understanding, scientific investigation, and practical reasoning. Conceptual understanding questions probe students' knowledge of essential scientific concepts including: facts, events, principles, laws, and theories. Scientific investigation questions probe students' abilities to use both cognitive and laboratory tools of science. This includes testing their ability to acquire new information, plan investigations, use a variety of scientific tools, and communicate results. Practical reasoning questions probe students' ability to use and apply science understanding in new, real-world applications.

The National Center for Education Statistics, in addition to releasing test items, also makes available data from their national sample. Mean scores for each test item are listed in several categories such as public school students versus private or parochial as well as for the total national sample. Each test item is also identified by type, content and process area. This facilitates comparisons between a target population and a comparable national sample. We used these data to compare achievement of students who have participated in a science program designed on the principles of PBS to that of a national sample.

<u>Purpose of the Study</u>

Our research group has been designing and studying PBS for nearly a decade (Blumenfeld, Krajcik, Marx, & Soloway, 1994; Blumenfeld et al., 1991; Krajcik, Blumenfeld, Marx, & Soloway, 1999; Krajcik, Blumenfeld, Marx, Bass, & Fredricks, 1998; Krajcik et al., 1996; Krajcik, Blumenfeld, Marx, & Soloway, 1994; Marx et al., 1994; Marx, Blumenfeld, Krajcik, & Soloway, 1997; Soloway, Krajcik, Blumenfeld, & Marx, 1996). We wanted to know if students in an inquiry-based science curriculum would perform as well as students nationally on achievement test items. We chose a school that had restructured their science program to address reform recommendations by using the principles of PBS. We also chose the science portion of the 1996 public release NAEP test. The significance of this study lies in its ability to offer supportive evidence for the science learning that takes place in PBS classrooms. If students in this project-based science program achieved at the same level as their peers nationally on this achievement measure, it would lend support to this reform and others like it. This might encourage otherwise reluctant educators to consider an inquiry-based program such as PBS to promote science understanding for their students.

Methods

<u>School Setting</u>

This study was conducted in a small alternative public high school enrolling about 450 students in an urban university town (population ~100,000) in the Midwest. The community served by the school is mostly white and middle to upper-middle class; students attending this school are demographically similar to the rest of the district. The school is considered an alternative high school and students throughout the district can elect to attend. Admission to the school at the time of this study was determined by a lottery system and by first-come, first-served enrollment (half of the incoming ninth grade class was selected by each procedure). There were no other requirements for admission. The student population had a wide variety of backgrounds and abilities; the school was not a magnet school for science nor was it considered among the top schools in the district on student achievement. Moreover, students interested in science generally did not attend the school. Rather, they chose to attend one of the district's two other high schools. These schools offered a more traditional science program, including multiple advanced placement science courses.

The school's philosophy from the time it opened over 25 years ago promoted independence and responsibility among the students. The campus, which was on the edge of the downtown business district, was open for all grades--students often left campus for lunch or on break periods--and the atmosphere was casual. Students addressed teachers by their first names; there were no bells and relatively little formal pressure was put on students to attend classes. The curriculum was college preparatory with most graduates attending college. However, it was not a high-powered, accelerated curriculum and no advanced placement courses were offered. There was a focus on the arts (drawing, painting, photography, music, and dance) at the school, but the school did not offer intramural athletic programs. The school took advantage of its location in the center of town and not far from the university by offering community resource courses, in which students could create their own courses with mentoring from teachers or community experts. Many students took advantage of the community resource opportunity with the result that there was continuous innovation and experimentation in the curriculum.

<u>Science Curriculum</u>

As part of a large research and development effort, the teachers in the science program worked with educational researchers from the University of Michigan to develop and implement a three year, integrated, project-based science curriculum for all students called Foundations of Science (FOS; Huebel-Drake, Finkel, Stern, & Mouradian, 1995). FOS was phased in as the science curriculum at this school, replacing separate earth science, biology, and chemistry courses at the 9th (FOS-I), 10th (FOS-II), and 11th grades (FOS-III). However, a separate physics course was available for 12th grade students. During the 1993-1994 school year, the FOS program was piloted in one 9th grade class. The program was extended to the entire 9th grade the next year (1994-1995), into the 10th grade in 1995-96 and the 11th grade in 1996-97. The 1996-97 school year also saw a change in the school scheduling system from a seven, 45-minute period day to a block-eight schedule with four 90-minute blocks Monday through Thursday and seven short 45-minute periods on Friday. Students met for science for two 90-minute blocks and one 45-minute block each week, so the amount of time in science was not increased compared to the school's previous class schedule.

During the year in which these data were collected, four teachers taught in the FOS program. All were certified to teach secondary science; their years of experience teaching high school science ranged from two years to about 25.

Throughout the year, students studied scientific subject matter by investigating broad questions and creating artifacts. Projects ranging from 7-8 weeks to 15-16 weeks were used to integrate earth science, biology, chemistry, and ecology. The FOS curriculum framework was based upon the PBS model; each course was designed around investigations of relevant “driving questions.” For instance, the question in FOS-I during the fall semester, “Is Traver Creek ecologically balanced?” provided students an opportunity to explore the biological, physical, and chemical aspects of their creek and to investigate connections between each of these factors. The second semester explored the driving questions: “Is our climate changing? Does it matter?” This project provided students with an opportunity to explore weather, global change and paleoclimatic effects (Huebel-Drake et al., 1995). Student artifacts created during these projects included concepts maps, essays, computer-based dynamic models, reports, and web pages.

Virtually all work in FOS was done in groups of 2-4 students, facilitating collaboration and communication. In addition, the FOS curriculum design integrated a high degree of computer technology. Students used computers as tools to gather information through telecommunications and probeware, analyze data, express results graphically or pictorially, create scientific models, and write reports. Laptop computers were available for student use, including the opportunity to take the machines home over night, at a ratio of roughly one computer for every two students.

<u>Students</u>

The students represented a range of racial, academic, and socioeconomic characteristics that correspond to district demographics, although the majority of students were white and middle- to upper middle-class. There was a slightly lower than district average of minority students and a slightly higher number of special needs students.

The Michigan Educational Assessment of Program (MEAP) also indicates that students participating in this study were comparable to white students throughout the state. The state reports the percent of students who pass the state achievement test in each subject test for every school in the state. In comparison to students at this district's two other high schools, our students scored marginally higher in science (66% vs. 65% and 54%), higher in reading (73% vs. 60% and 51%), but relatively the same in math (72% vs. 70% and 70%) and intermediate in writing (47% vs. 57% and 44%). The scores for three other white, suburban high schools in the county (science: 62%, 60%, 60%, reading: 69%, 52%, 62%, math: 75%, 73%, 77% and writing, 53%, 56%, 49%) also indicate that our students were not in the top bracket of achievement for white students.

In the spring of 1997 all students enrolled in FOS II and III were asked to complete all three sections of the 12^{th}-grade 1996 NAEP test in science. The FOS II students (n=85) were sophomores with 2 years of PBS instruction. The FOS III students (n=57) were juniors and therefore had 3 years of experience in this type of instruction. Only students who were absent on the day of test were not included in the sample.

<u>Procedures</u>

We used the 1996 public release version of the 12^{th}-grade test from NAEP for science. The official 1996 NAEP test consisted of 3 sections of questions. Section one included 15 items, all of which were based on a theme. Students were given a diagram and a description then were asked questions based on this scenario. Section two of the test included 16 items. These items included a general mix of content and process questions.

The third section, with only four items, included a performance task where students were given a set of equipment and asked to conduct an investigation and answer questions relating to the investigation. The NAEP's pool of questions was arranged in blocks. For example, 15 questions, designed around a theme for section one, were grouped together in a block. Likewise, questions were grouped in blocks of 16 for section two and blocks of 4 for section three. For each student a test was constructed by selecting a block of questions for each section of the test. A total of 15 blocks were available.

The public release information offered four blocks of questions, one for each of sections one and three, and two blocks for section two of the test. One block of questions was used for each section of the test we constructed. Only on section two, with 2 available blocks, did we have the opportunity to make a selection of the items our students would be given. We selected the block that most closely matched the content our students had studied. It should be noted, however, that the entire block of questions was used, as would be the case for the official NAEP test. Students were told that this was a research effort to explore the effectiveness of PBS, this test would have no bearing on their grade and the individual results would not be shared with their parents or teachers. Students were given the directions supplied by NAEP and 30 minutes to complete each section, the same amount of time offer by NAEP. The test consisted of a total of 35 questions, the same number as the NAEP. Unlike the usual NAEP procedure all students were given an identical version of the test.

The questions consisted of a mix of multiple choice, short constructed response in which students were expected to supply two to three correct ideas, and extended constructed response where students were expected to supply an extended explanation covering three or four ideas with perhaps a diagram. The test also included a performance portion in which students were asked to complete an extended task involving the separation of five substances with the use of a magnet, screen, and filter paper. This item was considered an extended constructed response item.

The short and extended constructed response questions were scored using rubrics supplied by NAEP. Our research group reviewed and discussed the rubrics in light of a sample of PBS student answers and the samples of student answers supplied by NAEP, after which one researcher scored all of the tests. This researcher did not know these students and was not familiar with their work. A second researcher then scored a random sample (one-third) of the tests. Inter-rater reliability was assessed through correlations between researchers for each individual question score to establish a level of confidence in the interpretation of the rubrics. Correlation coefficients ranged from 0.76 to 0.96 with a mean of 0.87.

We calculated the pass rate (p-value) for all questions according to the method supplied and used by NAEP. Multiple-choice questions were scored 0 (incorrect) and 1 (correct). The p-values for these items are the percent of students responding correctly. Short and extended constructed response items were also scored from 0 to 1. If, for example, the item had 3 categories of responses, incorrect was 0, partial was 0.5 and correct was 1. The p-values for these items are the means of each item.

We began with multivariate tests across all items in the respective analyses. When these tests indicated statistically reliable differences across the items, we followed with question-by-question comparisons of p-values between PBS students and the national averages supplied by NAEP, using a 2-tailed t-test for independent samples with 95% confidence intervals around each mean. Effect sizes were calculated for each comparison using the difference in means divided by the standard deviation of the national sample.

We compared PBS scores to the scores reported by NAEP for the total national sample. In order to make more stringent comparisons we also compared our scores to subgroups supplied by NAEP that most closely matched our student population. Since our sample consisted of nearly all white, middle class students we chose NAEP identified subgroups for white students and students not eligible for school lunch programs. NAEP usually reported higher p-values for these two categories than for public school students in the NAEP sample. Public school p-values were also very similar to and often lower than the overall p-values and therefore we did not use this category even though our school is a public school.

Results

The item p-values in this sample ranged from a low of 0.123 to a high of 0.944. The national p-values also had a very similar and large range (0.113 to 0.927). The correlation coefficient comparing p-values from our sample to the national sample is 0.77 ($p < .001$), indicating a close match in item difficulties for our sample compared with the national sample. Recall that our sample included students drawn from both the 10th and 11th grades (the former having participated in PBS for two years and the latter for three years). When we compared the means between the two course-level groups using a 2-tailed t-test we found significant differences for only three questions with third year students scoring higher. We also compared performance of male (n=69) and female (n=73) students. Four questions showed significant differences, one with females scoring higher and three with males scoring higher. We computed a multivariate analysis to test for teacher effects across all 35 items and found no differences for the four teachers (Pillai's Trace = .799; $F = 1.143$; $p = .192$).

<u>Comparison to the National Sample</u>

Information on p-values for the national sample was supplied by NAEP for all 35 items used in these comparisons. However, NAEP's reported scores did not match the rubric supplied by NAEP for one item, question 13 of section two. The NAEP rubric for this item indicated 3 categories whereas the NAEP reported scores indicated 4 categories. Therefore, we were unable to make comparisons between PBS students and the national sample for this item. The remaining 34 items were included in our analysis. Our first analysis was an omnibus test of group differences in means between the national and PBS sample. The multivariate analysis indicated a statistically reliable difference between the groups across all 34 items (Pillai's Trace = .800; $F = 125.98$; $p < .001$). Following this result, we computed analyses of mean differences for individual items. Means, statistics, and effect sizes are displayed for each item in Table 1.

[Insert Table 1 about here]

When we compared our sample to the national averages, PBS students scored significantly higher on more than half of the items (see the column labeled Total NAEP Sample in Table 2). The mean effect size for items significantly higher in this comparison was .52, which places PBS students in the 70th percentile of the national sample. When looking at the type of questions, PBS students scored higher than the national sample on a greater percentage of the extended constructed response items, followed by the short constructed response items, and a smaller percentage of multiple-choice items. The NAEP test items were also identified by content in three categories, earth science, physical science, and life science. PBS students scored higher than the national p-values on greater percentage of earth science items, followed by physical science items, and a smaller percentage of life science questions. The third category identified by NAEP was process type. PBS students out scored the national sample on most of the scientific investigation items, more than half of the conceptual understanding items, but only 1 of the 5 practical reasoning items.

We followed this analysis by comparing our PBS sample to two specific subgroups identified by NAEP. A multivariate analysis indicated a statistically reliable difference between PBS and students not eligible for the free lunch program across all 34 items (Pillai's Trace = .782; $F = 78.192$; $p < .001$). When compared to white students the results were similar (Pillai's Trace = .813; $F = 97.548$; $p < .001$). We compared p-values for each item from our sample to p-values for each of these groups (again see Table 1). The correlations between p-values for our sample and these two national subsamples were both 0.79 ($p < .001$). As we found in comparison with the total sample, the relative difficulty of items across our sample and various subsamples from NAEP were very similar. In general the p-values reported by NAEP were higher for students not eligible for the free lunch program and highest for white students when compared to p-values for the total national sample. NAEP reported p-values for minority students and students eligible for the lunch program were lower than the total national sample. Our sample did include a small number of minority students (it is not know if any students were eligible for the free lunch program).

Only three items that were previously significantly higher for our students compared to the total NAEP national sample were no longer significant when compared to students not eligible for the free lunch program. The mean effect size for items significantly higher in this comparison was .52, which places PBS students in the 70th percentile of this subgroup in the national sample. Two additional items were no longer significantly higher when compared to white students. The other 15 items were still significantly higher than the national average for both subgroups. The mean effect size for items significantly higher in this comparison was .48, which places PBS students in the 68th percentile of white students nationally. Of the five items that were no longer significantly higher, four were short constructed response and one multiple choice, three were earth science and two were physical science, and four were conceptual understanding and one was a practical reasoning item.

PBS students scored significantly lower on two items. For one of these items PBS students were significantly lower in all comparisons. This was a short constructed response, earth science, conceptual understanding item. On the other item PBS students scored significantly lower only when compared to white students. This item was a short constructed response, physical science, practical reasoning item.

Table 2 summarizes the statistical comparisons of the PBS sample to the national samples for categories of items. It is clear that the PBS sample scored significantly higher or equal to the national sample on the vast majority of items. On only a very small number of items did the PBS sample perform at a significantly lower level than the national sample.

[Insert Table 2 about here]

Discussion and Conclusion

The performance of our sample was relatively homogenous across grade, gender, and teacher, therefore we could use the item means for the total group of PBS students for comparisons to the national sample. The pattern of p-values for our sample was very similar to the national sample; PBS students scored low on items that the national sample scored low on and PBS students had higher scores on items for which the national sample had higher scores. Moreover, when we compared the distribution of item means for our sample to two subsamples (students not eligible for free lunch and white students) we found that the correlations remained high. These findings suggest that the patterns of difficulty for the national samples and PBS students are similar. Even with PBS inquiry-based curriculum, content that is difficult to learn remains difficult to learn and PBS students were more successful on content that is more easily understood nationally.

PBS students scored significantly higher than students nation wide on many items. Even when compared to groups that traditionally score higher on achievement tests (middle class and white students), on average the PBS students, including minorities, outscored the national sample on almost half of the items. Also, it is not known if any students in the national sample participated in a PBS program, therefore the national sample is not necessarily a non-PBS group. Still, this PBS group of 10^{th} and 11^{th} grade students performed higher on this set of 34 items than the national sample of 12^{th} grade, white students.

When we examine the types of questions for which PBS students scored higher, it is interesting to note that the percentage of items for which PBS students scored significantly higher increased as the length of the response increased. The format of PBS instruction encourages students to extend their thinking. Tasks and activities are designed to encourage students to express their ideas in a variety of ways. This may account for the margin observed in extended constructed response items.

PBS students also scored significantly higher on a larger percentage of the earth science items, then physical science followed by life science in all comparisons. There is no systematic relationship between the type of question and content, so PBS students are not scoring higher on earth science items because they are extended constructed response items. The teachers who designed the program in which these PBS students participated described it as integrating the content areas. The PBS students should have been exposed to each of the content areas assessed by NAEP in relatively equal portions over the course of a school year. However, at the time of this research, the PBS units did not yet emphasize biology content sufficiently; rather, the students were given more opportunities to study earth systems concepts.

When looking at process type, PBS students performed higher than the national sample on most of the scientific investigation questions. PBS students participate in investigations that are student designed and extend over time. They appear to acquire as much or more conceptual understanding as students nationally. On the other hand, PBS students scored higher on only one of the practical reasoning items. PBS is grounded by a driving question that is based on a real world issue. In spite of this emphasis on the real world, PBS students did not surpass (but did score as well as) the national sample on most practical reasoning items and actually scored lower on one item of this type. The practical reasoning items asked students to apply their knowledge to real life situations that they may not have encountered before. So although PBS is centered on a problem, students still need support in transferring their science understanding to new problems.

It is important to recognize some additional possible explanations for PBS students' success. It has been well established that students will perform better on items that contain content that they have studied regardless of the instructional method than they do on items containing content to which they have not had the opportunity to study (Walker & Schaffarzick, 1974). We do not know what content the students chosen for the national sample had studied or the type of instruction they experienced and they outscored PBS students on 2 of the 34 items. Also, the NAEP test is given to students in the 12th grade. These students may not have had a science course in two years (Hassard, 1992, p.168). Therefore while our sample was younger than the national sample, they did have a science course recently and many have completed three years of science. Many in the national sample may have completed only 2 years of science.

The school structure may also have contributed to the success of the PBS students. Students may have benefited from block scheduling. Although science classes met for the same amount of time per week as most schools, the 90-minute blocks helped students to stay focused on a topic for longer periods. The open atmosphere of the school may also have fostered self-directed, responsible learners. However, the state achievement test indicates that student at this school did not exceed other white suburban students in mathematic and were less able in writing. They did score higher in science than students at school offering advanced placement courses, which lends support to the PBS science program at this school.

PBS students did however score as well on most NAEP items and considerably higher on many other NAEP items than similar students nationally using conservative statistical methods. As encouraging as these results are this is only one indication of student success in Project-based Science. Other studies conducted at this same high school have measured student understanding in various ways. Stratford, Krajcik, & Soloway (1998) showed that most students demonstrated sufficient to appropriate science understanding when using computer-based dynamic models to learn content. Talsma (1999) also found large gains in student understanding as demonstrated both in student computer models and more traditional pre- and posttest assessment. We believe that these earlier findings along with the data reported here indicate that the PBS learning environment promotes student success in science.

This study shows that educators need not fear that students in inquiry-based science courses will be disadvantaged on large-scale achievement tests. PBS students performed as well or better on almost all of the items used to make comparisons to similar white and middle class students nationally. Project-based science incorporates the recommendations based on extensive research on learning made by national organizations including The American Association for the Advancement of Science and The National Research Council. Educators should be encouraged to use the PBS approach to implement reform in their schools.

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Table 1

Project-based Science (PBS) Compared To National Sample Subgroups by NAEP Test Item

NAEP Item Description[a]				Project-based Science	National Sample Subgroup								
Number	Type	Content	Process	(n = 142)	Total			Not Eligible Lunch Program			White		
				M	M	t	ES[b]	M	t	ES	M	t	ES
1-1	MC	ES	CU	.944	.927	0.75	.06	.947	-0.15	-.01	.969	-1.27	-.15
1-2	SCR	ES	CU	.708	.607	2.71**	.22	.638	1.86	.15	.655	1.37	.12
1-3	MC	ES	CU	.725	.576	3.79***	.30	.597	3.18**	.26	.632	2.30*	.19
1-4	SCR	ES	CU	.303	.269	1.48	.11	.274	1.22	.09	.303	0.00	.00
1-5	MC	ES	CU	.923	.830	3.79***	.25	.848	2.95**	.21	.866	2.25*	.17
1-6	MC	PS	CU	.845	.676	5.18***	.36	.696	4.41***	.32	.732	3.35***	.26
1-7	ECR	ES	SI	.721	.456	8.50***	.58	.476	7.39***	.52	.513	6.27***	.44
1-8	MC	PS	CU	.725	.638	2.23*	.18	.653	1.79	.15	.702	0.58	.05
1-9	SCR	ES	CU	.451	.174	10.11***	.90	.189	9.03***	.82	.216	7.76***	.70
1-10	ECR	ES	CU	.732	.515	7.84***	.61	.545	6.20***	.55	.583	4.99***	.44

(table continues)

Table 1 (continued)

Project-based Science (PBS) Compared To National Sample Subgroups by NAEP Test Item

NAEP Item Description[a]				Project-based Science	National Sample Subgroup								
Number	Type	Content	Process	(n = 142)	Total			Not Eligible Lunch Program			White		
				M	M	t	ES[b]	M	t	ES	M	t	ES
1-11	SCR	ES	CU	.641	.175	21.18***	1.66	.186	19.98***	1.58	.199	19.34***	1.51
1-12	SCR	ES	CU	.553	.393	4.09***	.48	.402	3.79***	.45	.437	2.92**	.34
1-13	SCR	ES	CU	.468	.369	3.19**	.27	.389	2.48*	.21	.428	1.27	.11
1-14	SCR	ES	PR	.363	.244	3.23**	.30	.266	2.65**	.24	.293	1.88	.17
1-15	ECR	ES	PR	.207	.202	0.19	.02	.213	-0.25	-.02	.226	-0.73	-.07
2-1	MC	PS	CU	.831	.804	0.77	.07	.822	0.27	.02	.835	-0.12	-.01
2-2	MC	PS	CU	.634	.572	1.43	.12	.582	1.17	.10	.593	0.91	.08
2-3	MC	PS	PR	.345	.396	-1.19	-.10	.394	-1.11	-.10	.416	-1.63	-.14
2-4	MC	LS	CU	.437	.431	0.13	.01	.455	-0.40	-.04	.447	-0.22	-.02
2-5	SCR	PS	CU	.606	.521	2.42*	.22	.553	1.46	.14	.588	0.50	.05

(table continues)

Table 1 (continued)

Project-based Science (PBS) Compared To National Sample Subgroups by NAEP Test Item

NAEP Item Description[a]				Project-based Science	National Sample Subgroup								
Number	Type	Content	Process	(n = 142)	Total			Not Eligible Lunch Program			White		
				M	M	t	ES[b]	M	t	ES	M	t	ES
2-6	SCR	ES	CU	.553	.219	19.91***	1.01	.248	16.32***	.87	.252	16.12***	.86
2-7	SCR	ES	CU	.701	.757	-2.11*	-.19	.768	-2.48*	.23	.779	-2.30**	-.27
2-8	SCR	PS	PR	.123	.113	0.49	.04	.115	0.38	.03	.130	-0.27	-.03
2-9	MC	PS	CU	.655	.639	0.38	.03	.645	0.24	.02	.687	-0.77	-.07
2-10	MC	PS	CU	.880	.576	9.90***	.62	.612	8.29***	.55	.646	7.29***	.49
2-11	SCR	ES	CU	.232	.157	3.06**	.32	.153	3.16**	.34	.171	2.45*	.26
2-12	MC	LS	SI	.479	.403	1.71	.15	.416	1.39	.13	.433	1.02	.09
2-13	SCR	PS	PR	omitted									
2-14	ECR	LS	CU	.252	.151	3.62***	.38	.166	3.00**	.31	.177	2.61**	.26
2-15	SCR	LS	CU	.416	.375	1.06	.09	.400	0.39	.04	.422	-0.17	-.01

(table continues)

Table 1 (continued)

Project-based Science (PBS) Compared To National Sample Subgroups by NAEP Test Item

NAEP Item Description[a]				Project-based Science	National Sample Subgroup								
Number	Type	Content	Process	(n = 142)	Total			Not Eligible Lunch Program			White		
				M	M	t	ES[b]	M	t	ES	M	t	ES
2-16	ECR	LS	CU	.265	.253	0.49	.05	.256	0.39	.04	.276	-0.42	-.04
3-1	ECR	PS	SI	.424	.163	8.90***	1.14	.173	8.51***	1.11	.197	7.65***	.93
3-2	ECR	PS	SI	.736	.654	3.47***	.23	.664	2.94**	.20	.686	2.06*	.14
3-3	ECR	PS	SI	.688	.570	3.67***	.32	.579	3.32***	.30	.619	2.18*	.19
3-4	SCR	PS	PR	.338	.389	-1.44	-.12	.400	-1.67	-.14	.433	-2.60**	-.22

[a]Type: MC-multiple-choice, SCR-short constructed-response, ECR-extended constructed-response; Content: ES-earth science, PS-physical science, LS-life science; Process: CU-conceptual understanding, SI-scientific investigation, PR-practical reasoning.

[b]Effect Size: effect size was calculated by the difference between the means divided by the standard deviation of the national sample.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 2

Percentage of Items Where PBS Student Score Significantly Higher Compared To Groups in the National Sample.

NAEP Item Characteristics	Number of Items	Comparisons to NAEP Samples[a]		
		Total	Not Eligible for Free Lunch	White
Type				
Multiple Choice	12	42	33	33
Short Constructed Response	14	64	50	36
Extended Constructed Response	8	75	75	75
Content				
Earth Science	16	75	69	56
Physical Science	13	52	38	38
Life Science	5	20	20	20
Process				
Conceptual Understanding	24	63	50	46
Scientific Investigation	5	80	80	80
Practical Reasoning	5	20	20	0
Total	34	59	50	44

[a]Percentages are calculated by the number of items for which PBS students scored significantly higher ($p < .05$) than the national sample divided by the number of items.

Appendix A

NAEP Test Items Used in This Study

1996 Assessment

SCIENCE-PUBLIC-RELEASE

Grade 12

Number of items: 35

Information about the Item Difficulty Available for Each Item

Item identification, a short item description, and the key (for multiple-choice items) are provided, in addition to information about the item dificulty, for each item. The items are identified by their position within a block and by their NAEP IDs. The NAEP IDs are used to identify items during the analysis of NAEP data in the summary of item level results in data almanacs, and in the secondary user data sources.

The numbers in the column labeled "P-Value" on the item statistic sheet vary for item types (multiple-choice and 2-category constructed-response items and constructed-response items with more than two categories). For the multiple-choice items and for the 2-category constructed-response items that were scored correct or incorrect the number in that column is the percent of students correctly responding to the item. This value is often called the p-value or the P+ for an item. For constructed-response items with more than two categories, the value in the column is the mean item score for the item.

For example, if the number of categories for a constructed-response item is 3 with a category/unsatisfactory/incorrect (category 1) worth 0 points, a partial category (category 2) worth 1/2 of a point and a complete category (category 3) worth 1 point, then a student can receive either 0, 1/2 or 1 point for his response to the item. The mean item score is the number that you would get if the scores on this item are averaged for all of the students in the assessment. This value varies from 0 to 1 just as the percent correct for a multiple-choice item could vary. It can be interpreted as an indication of where on the 0-1 scale for the item that an "average" student might score. For instance, if the mean item score for a 3-category constructed-response item is .8, then an "average" student would be expected to have a response in either category 2 (worth 1/2 or .5 of a point) or category 3 (worth 1 point). in fact it is a little more likely that the student would have a response in category 3, since .8 is closer to 1.0 than to .5.

INFORMATION ABOUT THE FRAMEWORK CLASSIFICATION CODES AVAILABLE FOR EACH ITEM

Following this description of the classification codes, there is a single sheet with NAEP ID numbers, short descriptions of the items, item keys(1-4 if the item is multiple-choice; blank of the item is open-ended), as well as the mean p-values for the items in the released block.

The classification codes for each item can be viewed within each item in the scoring guide.

Field 1)	**Program Profile:**
	N27S NAEP, year 27 of Science
Field 2)	**Grade:**
	1 Grade 4 only item
	1/2 Grade 4/8 overlap item
	2 Grade 8 only item
	2/3 Grade 8/12 overlap item
	3 Grade 12 only item
Field 3)	**Field of science:**
	PS Physical Science
	ES Earth Science
	LS Life Science
	Field science of subcontent area:
	The letter corresponds to the subcontent areas described in the Science Assessment and Exercise specifications for the 1996 National Assessment of Educational Progress.
Field 4)	**Physical Science:**
	A Matter and Its Transformations
	B Energy and Its Transformations
	C Motion
	Earth Science:
	A Solid Earth (lithosphere)
	B Water (hydrosphere)
	C Air (atmosphere)
	D Earth in Space
	Life Science:
	A Change and Evolution
	B Cells and Their Functions
	C Organisms
	D Ecology
Field 5)	**Ways of knowing and doing science:**
	SI Scientific Investigation
	PR Practical Reasoning
	CU Conceptual Understanding

Field 6)	**Theme:**	
	SYS	Systems
	MOD	Models
	PC	Patterns of Change
	NA	Not Applicable
Field 7)	**Nature of Science/Technology:**	
	NS	Nature of Science
	NT	Nature of Technology
	NA	Not Applicable
Field 8)	**Item Type:**	
	MC	Multiple-Choice
	SCR	Short Constructed-Response
	ECR	Extended Constructed-Response
	NA	Not Applicable

SECTION ONE

15 ITEMS

1996 Science Items

GRADE: 12 BLOCK: 27S7

ITEM	NAEP ID	SHORT DESCRIPTION	KEY	CONTENT	PROCESS	P-VALUE	RELEASE STATUS
1	K049801	WATER CYCLE: GASEOUS FORM MC	2	2	3	0.927	P
2A	K049802	WATER CYCLE: SOLID FORM OE		2	3	0.607	P
3	K049803	WATER CYCLE: SEPARATION OF IMPURITIES MC	3	2	3	0.576	P
4A	K049804	WATER CYCLE: ROLE OF FORESTS OE		2	3	0.269	P
5	K049805	WATER CYCLE: CAUSE OF EVAPORATION MC	4	2	3	0.830	P
6	K049806	WATER CYCLE: EVAPORATION V. TEMPERATURE MC	3	1	3	0.676	P
7A	K049807	WATER CYCLE: TEST TO RECOGNIZE WATER OE		2	1	0.456	P
8	K049808	WATER CYCLE: DECREASE IN HEAT CONTANT MC	1	1	3	0.638	P
9A	K049809	WATER CYCLE: CLOUD F0RMATION OE		2	3	0.175	P
10A	K049810	WATER CYCLE: LAKE H20 TO SNOW ON MOUNTAIN OE		2	3	0.548	P
11A	K089811	WATER CYCLE: WATER AS A RENEWABLE RESOURCE DE		2	3	0.175	P
12A	K049812	WATER CYCLE: PREVAILING WINDS OE		2	3	0.392	P
13A	K049813	WATER CYCLE: CAUSE OF DESERT CONDITIONS OE		2	3	0.369	P
14A	K049814	WATER CYCLE: FRESH WATER FROM 0CEAN WATER OE		2	2	0.244	P
15A	K049815	WATER CYCLE: S02 POLLUTION OE		2	2	0.218	P

Content:
1 = Physical Sciences
2 = Earth & space sciences
3 = Life sciences

Process:
1 = Scientific investigation
2 = Practical reasoning
3 = Conceptual understanding

SECTION 123

Section 123

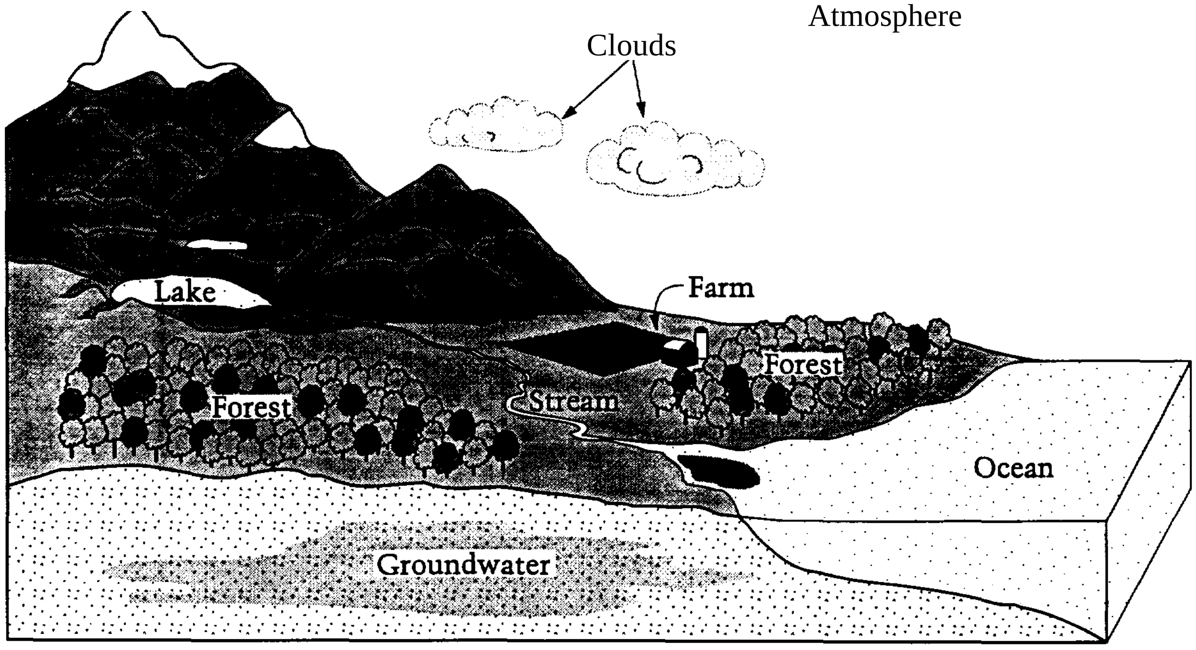
In this section, you will have 30 minutes to answer 15 questions. Mark your answers in your booklet. Fill in only one oval for each question or write your answer on the lines. Please think carefully about your answers. When you are writing your answers, be sure that your handwriting is clear,

Do not go past the **STOP** sign at the end of the section. If you finish before time is called, you should go over your work again.

PLEASE TURN THE PAGE AND BEGIN NOW.

GO ON TO THE NEXT PAGE

Section 123



The diagram above shows a region near the coast of a large continent. A range of high, snowcapped mountains lies near the ocean. There is a farm between the mountains and a forest.

The following questions ask you to think about water and the water cycle in the system shown in the diagram. In the system, water exists as a gas, a liquid, and a solid.

HE001355

1. In what part of the system does water exist primarily in a gaseous form?

- Ⓐ Lake
- Ⓑ Atmosphere
- Ⓒ Ocean
- Ⓓ Groundwater

HE001356

2. Where and in what form does water exist in a solid state in this system?

HE001357

____

____

____

____

____

3. In which part of the water cycle are dissolved solid impurities separated from the water?

- Ⓐ Cloud formation in the atmosphere
- Ⓑ Precipitation from the clouds
- Ⓒ Evaporation from the ocean
- Ⓓ Water flow from the lake to the ocean

HEO01362

Section 123

4. Describe what role the trees in the forests play in the water cycle in this system. HE001360

____

____

____

____

____

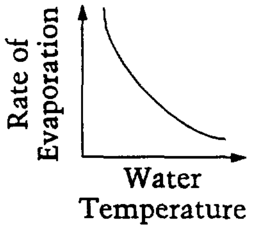
5. What is the main cause of water evaporation from the ocean?

- Ⓐ Wind and wave action along the shore
- Ⓑ Currents in the ocean
- Ⓒ Heat energy from the ocean floor
- Ⓓ Heat energy from the Sun

HE001358

6. Which of the following graphs shows how the rate of evaporation changes with changes in water temperature? HE001361

Ⓐ



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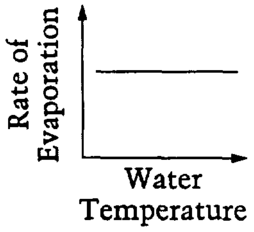

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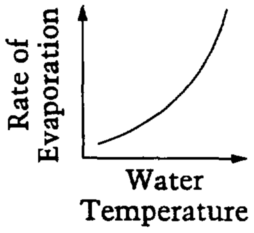

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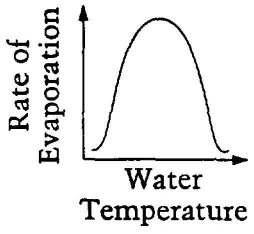


Section 123

7. Some students were studying water in the environment. They filled one sample jar with ocean water and another sample jar with fresh water from the lake. The labels on the jars fell off, and the water in both jars looked the same. Describe a test, other than tasting or smelling the water, that the students could do to determine which jar held the ocean water and which jar held the lake water. Explain how the test would work. XI000871

8. During which of the following processes is there a decrease in the heat content of the form of water indicated?

Ⓐ Ice as it forms on a lake

Ⓑ Water droplets as they fall to the ground

Ⓒ Water as it evaporates from a pond

Ⓓ Snow as it melts on a mountainside

HE001363

9. Explain how clouds can form as air rises. You may draw a diagram as part of your explanation.

HE001364

Section 123

10. Describe how water in the lake can become snow on the mountains in the system shown in the diagram on page 2.

HE001365

11. Referring specifically to the system shown in the diagram on page 2, explain why fresh water is a natural resource that is <u>renewable.</u>

HE001366

12. In the system shown in the diagram on page 2, the prevailing winds blow from the ocean toward the mountains in September. In June, however, the winds blow mostly from the mountains toward the ocean. In which month, June or September, would the farm get more precipitation? Explain your answer.

HE001368

13. Further inland on the continent, just beyond the mountain range shown in the diagram on page 2, there is a desert that receives very little precipitation. Give an explanation of why this desert receives such a small amount of precipitation. HE001369

14. Describe a technological process that can be used to obtain fresh water from ocean water. HEOO1367

15. Suppose that a coal-burning power plant near the farm releases sulfur dioxide ($S0_2$) into the atmosphere. Write a chemical equation for the reaction that occurs between sulfur dioxide and water. Describe how the product of this reaction would affect the fish in the lake and the trees and other plants on the mountains and in the forests. HE001371

SECTION TWO

16 ITEMS

1996 Science Items

GRADE: 12 BLOCK: 27S20

ITEM	NAEP ID	SHORT DESCRIPTION	KEY	CONTENT	PROCESS	P-VALUE	RELEASE STATUS
1	K057101	RECOGNIZE ECLIPSE PROGRESSION MC	3	2	3	0.804	P
2	K057201	PROPERTY SHOWN BY STAR COLOR MC	4	2	3	0.572	P
3	K057301	CAUSE OF SIZE CHANGE OF CELLS IN FLUID MC	1	3	1	0.330	P
4	K057302	CELLS IN FLUID: ACCURACY OF CONCLUSION MC	4	3	1	0.431	P
5A	K057401	TESTING SOIL AFTER FLOOD OE		2	2	0.521	P
6A	K057501	HOW TO KEEP ICE CREAM COOLER THAN 0xC OE		1	2	0.219	P
7A	K057601	HOW TO REDUCE RISK OF HEART DISEASE OE		3	2	0.757	P
8A	K057701	RISK OF INFECTION FROM PEROSN WITH MALARIA OE		3	2	0.112	P
9	K057801	USE OF AMNIOCENTESIS MC	2	3	3	0.639	P
10	K057901	EVIDENCE FOR CONTINENTAL DRIFT THEORY MC	3	2	3	0.576	P
11A	K058001	EFFECT OF WAVES ON BOAT MOVEMENT OE		1	3	0.157	P
12	K058101	RELATIVE SPEED OF FLIGHT ATTENDANT MC	2	1	3	0.403	P
*13A	K058201	HOW TO PREVENT DAMAGE BY SUBFREEZING TEMPS OE					
14A	K058301	ENERGY TRANSFORMATIONS AND ENERGY DIFFS OE		1	2	0.162	P
15A	K058401	CLIMATE/ECOLOGY OF ALASKA LONG AGO OE		2	3	0.375	P
16A	K058501	GENOTYPE PRDCTN BASED ON EARLOBE PHENOTYPE OE		3	3	0.278	P

Content: 1 = Physical Sciences
2 = Earth & space sciences
3 = Life sciences

Process: 1 = Scientific investigation
2 = Practical reasoning
3 = Conceptual understanding

SECTION 123

In this section, you will have 30 minutes to answer 16 questions. Mark your answers in your booklet. Fill in only one oval for each question or write your answer on the lines. Please think carefully about your answers. When you are writing your answers, be sure that your handwriting is clear.

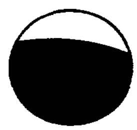
Do not go past the **STOP** sign at the end of the section. If you finish before time is called, you should go over your work again.

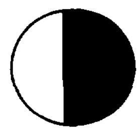
PLEASE TURN THE PAGE AND BEGIN NOW.

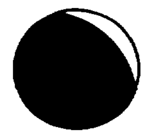
Section 123

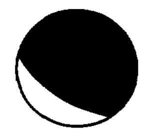
Noon | 12:30 p.m. | 1:00 p.m. | 1:30 p.m.

1. Four stages in the progression of a solar eclipse are shown above. How would the eclipse most likely look at 2:00 p.m.? HE001802

Ⓐ 

Ⓑ 

Ⓒ 

Ⓓ 

2. The color of a star provides a measure of its

Ⓐ size

Ⓑ mass

Ⓒ composition

Ⓓ surface temperature

HE001693

Questions 3-4 are based on the following situation and data table.

A laboratory technician places red blood cells into three different solutions. Observations are recorded each minute for five minutes.

Solution	Time				
	1 min.	2 min.	3 min.	4 min.	5 min.
Solution 1	No change	Cells are slightly larger.	Cells are much larger.	Cells are huge.	Cells are gone.
Solution 2	No change	No change	No change	No change	No change
Solution 3	No change	Cells are slightly smaller.	Cells are much smaller.	Cells look wilted.	Nothing that looks like a cell can be found.

HE001894

3. Which of the following best explains what is causing the red blood cells in solution 1 to change size over the five-minute period?

Ⓐ Solvent is entering the cells faster than it is leaving the cells.

Ⓑ Solute is entering the cells faster than it is leaving the cells.

Ⓒ The cells are making new protein.

Ⓓ The cell membranes are dissolving.

HE001895

4. The laboratory technician concludes that red blood cells cannot function in any fluid except serum. Which of the following best characterizes this conclusion?

Ⓐ It is accurate on the basis of the information given.

Ⓑ It is accurate because the cells changed in all the solutions but one.

Ⓒ It is inaccurate because the cells were outside the body.

Ⓓ It cannot be substantiated with the data provided.

HE001896

5. You live along a major river, and your farm was flooded this spring. There are many larger farms and a few factories upriver that were also flooded. Provide two flood-related reasons for testing your soil before planting this year. HE001794

6. You are taking ice cream in a cooler to a picnic and want to keep the ice cream colder than 0°C for several hours.

How could you do this?

Explain how your method works. VK000016

7. Heart disease is a major cause of death in the United States. Describe two ways a person can reduce the risk of heart disease. HE001717

8. A person has just returned to the United States from the tropics and is found to have malaria. What is the risk of other people catching the disease from this person?

Explain your answer. VK000013

9. Amniocentesis can be used to detect which of the following in a fetus?

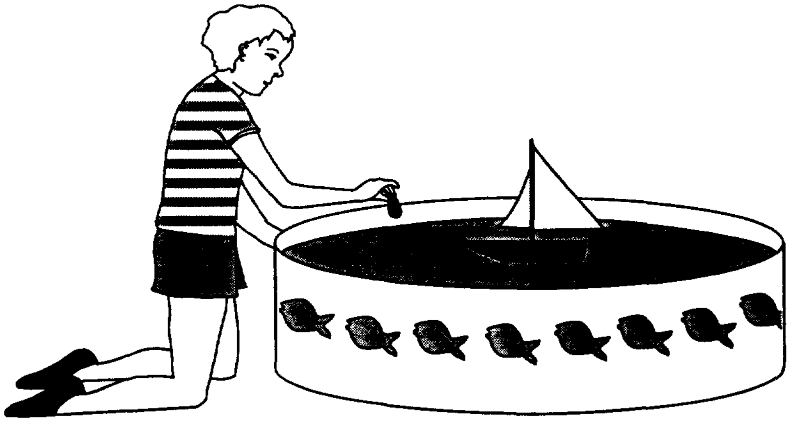
- Ⓐ Cholera
- Ⓑ Down syndrome
- Ⓒ Measles
- Ⓓ Acquired immunodeficiency syndrome (AIDS)

VK000036

10. Of the following statements, which best supports the continental drift theory?

- Ⓐ All oceans are salty.
- Ⓑ Igneous rocks are found on all continents.
- Ⓒ Fossils of the same species of extinct land plants have been found in both South America and Africa.
- Ⓓ Early humans migrated to North America over a land bridge from eastern Asia.

HE001789



11. A toy boat is floating in a wading pool. A child drops a stone into the pool to make small waves. How does the boat move in the presence of these waves?

Why does it move in this way? HE001863

12. An airplane is flying at a speed of 170 meters per second (m/s) relative to the ground. A flight attendant is walking at a speed of 2 meters per second to the rear of the plane. Relative to the ground, the flight attendant has a speed of

- (A) 2 m/s
- (B) 168 m/s
- (C) 170 m/s
- (D) 172 m/s

VK000030

Section 123

13. List two specific types of problems or damage to houses and cars that can occur from subfreezing temperatures. Explain how each type of problem or damage can be prevented from happening by using means other than direct heat. VK000017

14. Coal is burned in a power plant that produces electricity. In a house miles away, a lightbulb is turned on. Describe the energy transformations involved.

Compare the amount of energy released in one hour by burning the coal, the amount of energy received from the power plant in one hour by the house, and the amount of light energy produced in one hour by the lightbulb. Explain any differences among these three amounts of energy. HE001722

15. The petroleum fields on the North Slope of Alaska area major energy source. What does the presence of these fields indicate about the climate and ecology of the North Slope millions of years ago?

Climate:

Ecology: HE001791

16. A mother with attached earlobes and a father with free earlobes have 5 children – 4 boys and 1 girl. All of the children have the father's type of earlobes. What can be predicted about the genotype of the father? Construct a genetic diagram to support your prediction. What additional information, if any, would you need to determine the genotype of the father? Explain. HE001855

STOP

SECTION THREE

4 ITEMS

1996 Science Items

GRADE: 12 BLOCK: 27S4

ITEM	NAEP ID	SHORT DESCRIPTION	KEY	CONTENT	PROCESS	P-VALUE	RELEASE STATUS
1A	K049601	SEPARATION: USE OF EQUIPMENT OE		1	1	0.179	P
2A	K049602	SEPARATION: SEPARATION OF MIXTURE OE		1	1	0.653	P
3A	K049603	SEPARATION: DESCRIBE SEPARATION OF MIXTURE OE		1		0.570	P
4A	K049604	SEPARATION: SEPARATION OF SUBSTANCE IN H20 OE		1	**2**	0.390	P

Content:
1 = Physical Sciences
2 = Earth & space sciences
3 = Life sciences

Process:
1 = Scientific investigation
2 = Practical reasoning
3 = Conceptual understanding

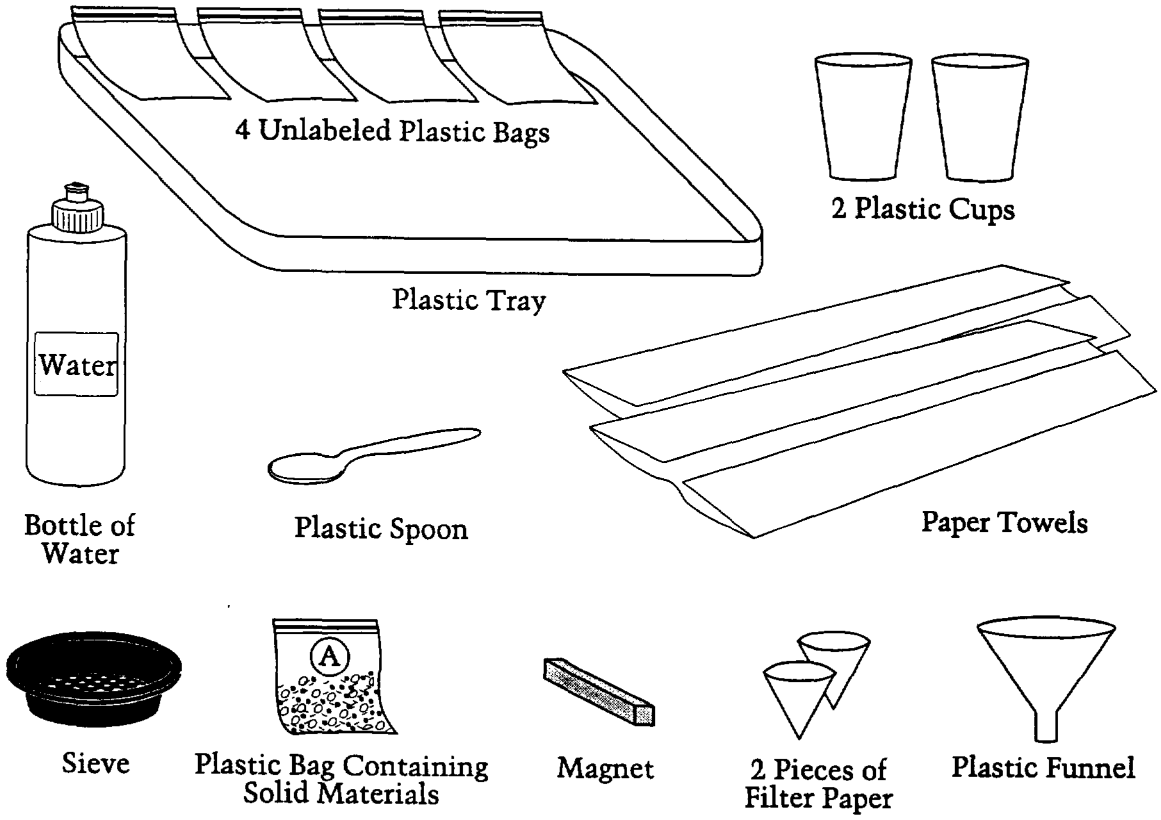
SECTION 123

Section 123

SEPARATION

Separating a Mixture of Solid Materials

For this task, you have been given a kit that contains materials that you will use to perform an investigation during the next 30 minutes. Please open your kit now and use the following diagram to check that all of the materials in the diagram are included in your kit. If any materials are missing, raise your hand and the administrator will provide you with the materials that you need.



STOP

Section 123

<u>The Investigation:</u> The plastic bag(A) contains a mixture of five solid materials. Your job is to design a procedure for separating the materials in the mixture using the equipment in your kit.

It is known that the mixture contains& different substances:

Three different metals

Sand

Salt

You will be asked to write a complete plan of all of the steps in your separation procedure. You will also be asked to save samples of the separated materials in small plastic bags.

As you perform this task, follow the directions step-by-step and write your answers to the questions in the space provided in your booklet.

<u>Important Note:</u> If you need more of the mixture, raise your hand and the administrator will give you another bag. 0P000725

1. Look at the contents of plastic bag (A) without opening it. What properties do the substances in the mixture have that would allow the following equipment to be used to separate the mixture?

0P000722

Magnet:

Filter paper:

Sieve:

2. Now use this equipment to separate the five materials in the mixture. Each time you successfully separate a material from the mixture, place this separated material in one of the small unlabeled plastic bags. The materials that you separate <u>do not</u> have to be 100 percent pure, but they should be as pure as possible. Each separated material should be placed in its own plastic bag. The bags with the separated materials will be collected after you have completed the task.

[Notes: 1) If you have collected a material in the filter paper, you do not need to separate the material from the filter paper. Just put the filter paper in the plastic bag. 2) If you end up with one of the five materials dissolved in water, you can leave this material in the cup.]

0P000723

3. Based on what you discovered as you worked to separate the materials in the mixture, write in the space below step-by-step instructions that would allow someone else to separate all five solids using the same set of equipment. OP000724

4. Suppose that you have a sample of water in which an unknown solid substance has been dissolved. Describe a procedure that you would use to effectively separate the substance from the water. 0P000726

Cleaning Up

Pour any water that you used into one of the plastic cups and leave this cup on your desk for someone to collect. Wipe up any spills with the paper towels. Someone will collect the paper towels and four unlabeled plastic bags. Put everything else back into the large plastic bag.

FOR ADMINISTRATIVE USE ONLY

	CP	SP	IF	SD	ST
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0