Impact of an Ecohydrology Classroom Activity on Middle School Students' Understanding of Evapotranspiration

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ABSTRACT Current trends in ecological research emphasize interdisciplinary approaches for assessing effects of present and predicted environmental changes. One such emerging interdisciplinary field is the discipline of ecohydrology, which studies the feedbacks and interactions between ecological and hydrological processes. However, interdisciplinary science, which includes ecohydrology and other fields, has not yet been effectively translated into many K–12 curricula. We adapted an ecohydrological research project, originally conducted at the Biosphere 2 research apparatus, for use in a middle school classroom. The experiment focuses on describing the effects of changes in landscape vegetation cover on the partitioning of evapotranspiration, the major component of the water budget, into plant transpiration and soil evaporation. The 1-week long experiment was conducted by Grade 6 students ($n = 82$) in classrooms in Oro Valley, AZ. Students completed pre- and post-experiment tests designed to assess their general understanding of the components of evapotranspiration as well as the scientific procedures that can be used to differentiate them. Our results show significant improvement between the pre- and post-experiment evaluations on the understanding of the water cycle concepts, particularly those associated with evapotranspiration. This improvement illustrates how the incorporation of experimental knowledge can constitute a key instrument to successful delivery of scientific information in the classroom. We discuss how current scientific research can be effectively incorporated into the science curriculum, which in turn can be used as an instrumental tool to produce scientifically relevant data.

Incorporating current scientific research into K–12 education curricula has been an important challenge for both scientists and educators. In particular, there is a recognized urgency to improve scientific literacy in both students and the general public as a mechanism to bring society as a whole to make informed policy decisions about current and predicted changes in the environment (Hurd, 1997; National Research Council, 2006). In education, particularly at the K–12 level, content about the interactions between human activities and the natural world has traditionally been delivered by the scientific field of ecology (Jordan et al., 2009). Science educators have recognized the importance of transitioning from declarative to procedural knowledge with an emphasis on teaching scientific inquiry for delivering science content more effectively in the classroom (Orr, 1992; Torp and Sage, 2002; Finn et al., 2002, Jordan et al., 2009). Specifically, the process of providing students the opportunity to carry out their own project in a relatively short period of time can be a particularly successful strategy to deliver ecological content (Colley, 2006).

Inquiry-based approaches to teaching the scientific method and research processes have been implemented and embraced by middle school curricula (Steel et al., 2004). By actively engaging in hands-on activities and inquiry-based experiments, students acquire a feeling of ownership and interest in the scientific process that enhances their overall experience and desire to continue acquiring and sharing scientific knowledge. Along with

Impact Statement

Our project is a shining example of integrating K–12 science education into ongoing scientific research. Scientists communicate their work to students, who not only interact with scientists, but also participate in research, generating useful data. This closes the loop in the interaction between science and education. The study investigates the partitioning of evapotranspiration, the largest component of the water budget, into evaporation and transpiration, with important implications for our understanding of the water budget.

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classroom experimentation, communication of actual research results and interactions with scientists have been recognized as successful ways to promote interest in science, particularly ecology, in K–12 students (Kats et al., 2008). When students develop personal connections with scientists and their research, they are more likely to see science as more relevant to their lives, and potentially as a viable career (Hill et al., 1990; Fusco, 2001). Thus, these interactions not only improve the student's perception and understanding of science, but they also provide an opportunity to incorporate current scientific content into the classroom, making the curriculum more relevant to the social reality outside of the school.

Current environmental changes not only affect individual components of ecosystems, but also operate within interactions and feedbacks between ecosystem processes (Pickett et al., 2001; Peters et al., 2004). This has increased the necessity of developing interdisciplinary research fields such as ecohydrology, plant ecophysiology, and biogeochemistry. The complex nature of ecological processes, where natural, physical and even the social sciences converge, imparts a major challenge to teaching ecology in basic education levels (particularly, but not limited to, K–12 education). Properly communicating causal mechanisms (Grotzer and Basca, 2003) and feedback cycles (Carlsson, 2002) are key to engaging students in the study of ecology and ecosystems. Finding ways to introduce students to these processes and mechanisms using hands-on activities is relevant to enhancing their familiarity with the subject. Notably, the use of water-related processes, which integrate a suite of biological and physical mechanisms, could represent an important topic that constitutes a building block for children to understand ecosystem processes (Covitt et al., 2009). The water cycle provides a fundamental tool to teach students not only about the role of water in the ecosystems, but also about the interactions between humans and the environment through water and land use practices. Educators can use these water-mediated interactions between physical, natural, and social processes as the building block to develop curricular programs that can forge connections between students, science, and the environment (Varelas et al., 2001). In particular, the interactions between water cycle and ecological processes provide an important opportunity to incorporate interdisciplinary science into science curriculum.

The interdisciplinary field of ecohydrology seeks to understand the feedbacks and interactions between ecosystems and the water cycle (Rodriguez-Iturbe, 2000; Van Dijk, 2004; Breshears, 2005). One of the fundamental challenges in ecohydrology is to understand the dynamics of evapotranspiration, the dominant component of the water budget (Wilcox et al., 2003; Huxman et al., 2005). However, the scientific community is still lacking studies that describe how evapotranspiration is partitioned into its major components—soil evaporation and plant transpiration—in response to changes in vegetation cover. This knowledge has important implications for understanding the biological feedbacks in the water cycle, a key element of global change science (Williams et. al. 2004; Huxman et. al. 2005). One of the first attempts to describe the effect of changing vegetation cover on the partitioning of evapotranspiration was carried out at the Biosphere 2 apparatus in Oracle, AZ, between May and November 2008 (Wang et al., 2010). The results from this study (Wang et al., 2010) illustrate how the partitioning of evapotranspiration at the landscape scale responds to changes in tree cover in the landscape. This experiment, which used the unique logistical capabilities of the Biosphere 2, highlights the systematic and interactive effects of vegetation cover in hydrological variables that influence ecosystem processes and properties.

While running the study at the scale of the Biosphere 2 apparatus is critical to directly test hypotheses about the physical and physiological mechanisms that govern the relationship between the partitioning of evapotranspiration and the amount of vegetation cover in the landscape, there are still other drivers of this relationship that were not included into the study which require further experimentation. In particular, a fundamental aspect that requires initial exploratory data collection to help improve current knowledge (both hypothetical and experimental) is the sensitivity of evapotranspiration partitioning to variations on the physical characteristics of vegetation and climatic variables (Lawrence et al., 2007). We identified a key opportunity to develop such exploratory data collection while simultaneously providing a unique educational experience. With this purpose, we developed an adaptation of the large-scale experiment developed at Biosphere 2 to explore some of these effects associated with variations in the type of vegetation, while making the study amenable to a hands-on educational activity in 6th grade classrooms in Oro Valley, AZ.

This project is particularly relevant for the 6th grade classroom for several reasons. The space and time required, as well as the plant species used, can be modified to the convenience and limitations of the classroom (Villegas et al., 2009a). Also, the experiment provides the possibility for participation in data collection by every student in a classroom. From a curricular point of view, the project uses mathematics, graphing, and technology for generating, processing, and explaining experimental data. The project is well aligned with multiple portions of the 6th grade education standards including scientific inquiry, Earth system processes, and science and technology (Kuhn, 2002; Michaels et al., 2008; NRC, 2006). Further, the project provides extended opportunities for follow-on scientific questioning, hypothesis generation, data exploration, and experimentation.

In the following sections we present the adaptation of the on-going interdisciplinary research project from Biosphere 2 into a local middle school curriculum. We examine whether the students' understanding of the water cycle and the role of vegetation on it responded to the execution of this activity via the application of pre- and post-experiment tests. The main objectives of this project were: (1) to provide students with a hands-on approach to study the water cycle, with specific emphasis on the process of evapotranspiration, and (2) to quantitatively assess if the development of a hands-on experimental activity, combined with the presence of scientists in the classroom, can have an effect on the students' knowledge and understanding of the water cycle and its relation to other environmental processes. Finally, we discuss how the incorporation of experimental knowledge can constitute a key instrument to successfully deliver scientific information in the classroom and also how data and information generated in the classroom can be useful for scientists in their specific field of study.

Materials and Methods

Classroom Activity

This classroom experimental activity is designed to explore the partitioning of evapotranspiration into its two major components—evaporation from the soil and plant transpiration—as a function of vegetation cover. The experiment uses a series of arrangements of potted plants and pots with bare soil to create different proportions of vegetation cover. Each arrangement consists of a total of 20 pots, organized in a 5 × 4 matrix. Pots with plants are considered sources of transpiration whereas bare soil pots are considered sources of evaporation. The experiment is developed in a series of four runs, corresponding to four levels of vegetation cover, with each run taking 24 hours to complete. The term "run" refers to a specific arrangement of pots that encompasses both the proportion and spatial arrangement of plants and soil pots. Each run starts with the addition of water, followed by weighing both plant and soil pots, and finishes with re-weighing the following day (ideally 24 hours after water was added and the initial weight recorded). Water loss from each pot (which accounts for evaporation in soil pots and transpiration in pots with plants) is calculated as the difference between the final and initial weights. This procedure assumes that there is no drainage from the bottom of the pots, and the only possible mechanism for water loss is via evaporation and/or transpiration. The experiment also assumes that evaporation from the soil in pots with plants is negligible. This assumption is reasonable when, as in this case, the experiment is conducted with plants that offer a complete cover of the soil surface in the pots (Lawrence et al., 2007). The complete details of the procedure and materials for this experiment have been described elsewhere and are freely available online (Villegas et al., 2009a).

During the experiment, we used a Microsoft Excel workbook for data entry. The spreadsheet was designed so that the spatial arrangement of the cells for data entry corresponded to the spatial arrangement of the pots in each run. The spreadsheet cells were set up to automatically compute differences in plant weights once data were entered, and the results were displayed in a graph. Examples of the workbook are available in Villegas et al. (2009a). The classrooms in which we conducted the experiments were equipped with electronic whiteboards that were used to display the spreadsheet on the projection screen, and students entered their data using the interactive whiteboard interface. As students finished weighing their pots, they entered the weight into the appropriate cell of the workbook and the workbook cell computations immediately updated the totals and differences between previous and new pot weights; this in turn updated the graph displaying the ratio of evaporation to combined evapotranspiration.

Student Learning Assessment

Participants

Four 6th grade classes in an Arizona middle school were chosen to participate as a pilot in this outreach effort due to the natural alignment of 6th grade science standards (Arizona Department of Education, 2005; Krajcik et al., 1998; NRC, 2006; Roth and Lee, 2004) to the principles explored in the experiment. There were 82 students who completed both the pre-test and the post-test. Ten additional students were present for only the pre- or post-test; their data were not included in the analyses. The final sample included 42 boys, 37 girls, and 3 students whose gender was not identified.

Procedure

Students completed the pre-test during their science class period on the school day before the experimental activity started, under the supervision of their science teacher. After the pre-test, students listened to a 45-minute detailed presentation by the lead scientist of the project, supported by pictures and other material relevant to the experiment, that incorporated the background, principles, and procedures of the activity that would be conducted the following school-week, and how it related to the larger-scale project being conducted at the Biopshere 2 apparatus. On the first day of the school-week, two trays of pots were delivered to each classroom. The data collection portion of the experiment ran for 4 days. On the last day of the study, students completed the post-test under the supervision of their teachers, who collected the tests and returned them to the researchers for scoring and analysis.

Pre- and Post-Tests

Students' learning was assessed from their responses to a study-specific test that was applied before and after the experiment was carried out. The test addressed concepts of evaporation and transpiration, understanding of weight, scales of weight and dimensions, and problem solving strategies. The 11 question test included one definition item (yielding up to 3 points), four true–false items (yielding 1 point each), three multiple-choice items (yielding 1 point each), and three items that focused on concepts of weight: one open-ended problem (yielding up to 2 points depending on the quality of the answer), one involving conversion between units of weight (yielding 1 point), and one involving concepts of scale/dimension (yielding 1 point). Possible scores ranged from 0 to a maximum of 14 points. The test items are presented in Appendix A.

Statistical Analysis

Students' responses to the questions in the pre- and post-tests were scored and then summed to yield a total score for each test. Results from the pre- and post-tests were compared using matched-pairs *t*-tests. Results are considered significant at an alpha-level of 0.05.

Results

Mean scores for the pre- and post-tests are presented in **Fig. 1.** Overall, students showed improvement on the test as a result of the activity. A matched-pairs *t*-test indicated that the improvement was significant [$t(81) = 9.530$, $p < 0.001$ Fig. 1A]. Individual question analyses indicate that overall, student performance in the test was improved by the activity. However, in some cases, the performance did not improve as a result of the activity (Fig. 1B, 1C).

Definition. The first test question required students to define "evapotranspiration" by listing the three key components: "water," "evaporation," and "transpiration." Students received 1 point for each correct term listed, yielding a score from 0 to 3. Fill-in-the-blank questions tend to be challenging for students, and performance on this item was generally poor. However, students did show significant improvement on the post-test [$t(81) = 6.138$, $p < 0.001$; Fig. 1B, 1C].

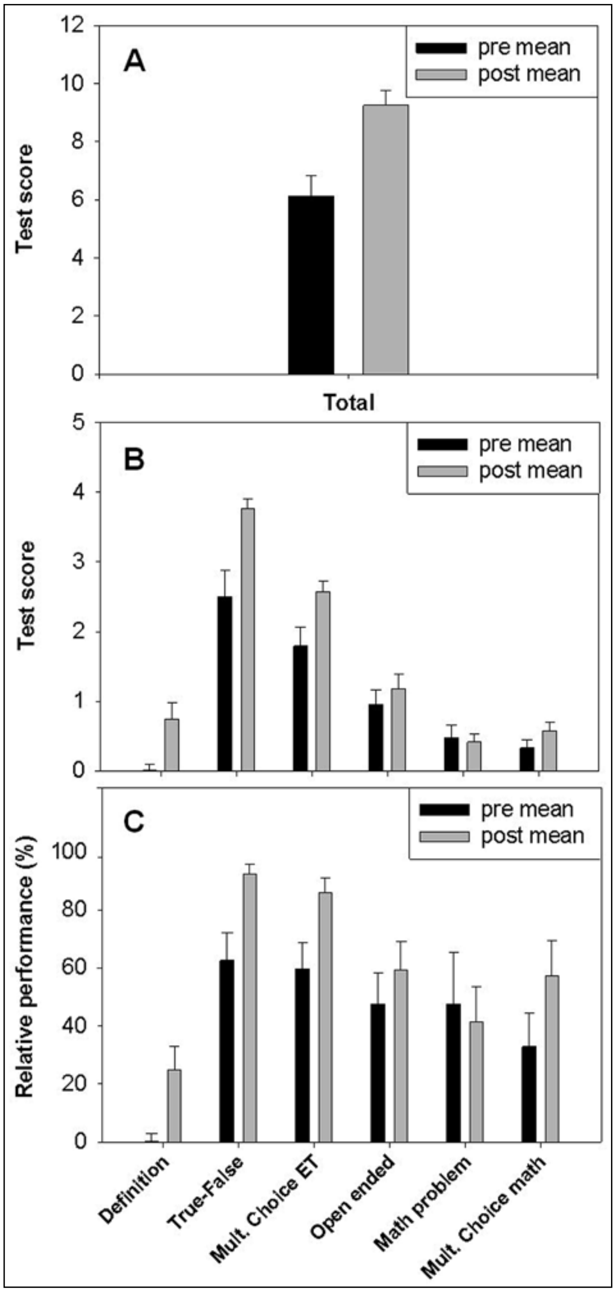

Fig. 1. (A) Overall mean results from the pre- and post-assessment tests applied to the students before and after the completion of the experiment; (B) mean results from each question type for pre- and post-experiment assessment; and (C) Normalized results for each question type for pre- and post-experiment assessment. Error bars indicate 95% confidence intervals around mean values.

True–False Questions. Correct responses on these four items were summed for each student to yield a true–false score ranging from 0 to 4. Results indicate that students showed significant improvement on the post-test [$t(81) = 7.419$, $p < 0.001$; Fig. 1B, 1C]. In this case, average improvement was on the order of one additional true–false item correct on the post-test.

Multiple-Choice Questions. Correct answers were summed for these items, yielding a score of 0 to 3 for each student. Our results indicate that improvement from pre- to post-test was significant [$t(81) = 5.854$, $p < 0.001$; Fig. 1B, 1C].

Open-Ended Weight Problem. Students wrote out their solution strategy in the answer space below this question. These answers were coded as follows: Students received a score of 0 if they left the question blank; 1 point if they attempted to answer but the answer was incorrect, incomplete, or irrelevant (e.g., "use a scale," "get more food," "drink some water"); 2 points for a clear and accurate explanation ("weigh the person after lunch and subtract his initial weight to find the difference"). Our results indicate that students significantly improved from pre- to post-test [$t(81) = 2.387$, $p < 0.05$; Fig. 1B, 1C].

Math Problem. Students were asked to calculate the number of grams in 1 pound, given the information that there are 16 ounces in 1 pound and each ounce is equivalent to 28.35 grams. Students received a score of 0 for a blank or incorrect answer, and a score of 1 for a correct solution. Mean scores for this question on the pre- and post-tests were not significantly different [$t(81) = 0.727$, ns; Fig. 1B, 1C].

Scale Problem. On this multiple-choice item, students had to choose the best scale for obtaining one's weight. Students received a score of 0 for an incorrect choice and a score of 1 for choosing the correct option. There was significant improvement from pre- to post-test on this item [$t(81) = 3.965$, $p < 0.001$; Fig. 1B, 1C].

Discussion

In this study, 6th grade students conducted an experiment adapted from a current scientific project being carried out at the University of Arizona Biosphere 2 apparatus. Over the course of 1 week, students examined the effect of increasing vegetation cover on the partitioning of evapotranspiration into its major components (evaporation from the soil and transpiration from plants). The students obtained data by calculating the differential weight loss in pots with either bare soil (sources of soil evaporation) or a plant (sources of transpiration) for a 24-hour period. They repeated the procedure, varying the ratio of plants to soil, and entered their data into a spreadsheet that allowed real-time display of data and results as the activity progressed. By participating in this experiment, the students became active "scientists in-training" with their results contributing directly to the larger evapotranspiration study performed by University of Arizona researchers (Villegas et al., unpublished data, 2010).

We conducted pre- and post-assessment tests to evaluate the effect of this activity on the students' understanding of the water cycle and its relation to other environmental processes. The results indicate that students performed significantly better on the post-test for questions about evaporation, transpiration, and concepts of measurement (Fig. 1). Students were more likely to provide accurate definitions for key terms, to recognize the factors and conditions that influenced evapotranspiration, and to suggest reasonable strategies for calculating weight (Fig. 1B). Because the same test was used for both the pre- and post-test, it is possible for students to learn from one exposure to a test and thus perform better on a second attempt simply because they have seen the questions before (Schaughnessy et al., 2009). However, this did not seem to be the case in this study, because students did not improve uniformly across the items in the test; in fact, students did not improve at all on the mathematical problem that required them to convert from pounds to grams (Fig. 1B). Thus, the improvement in their performance does not seem to be solely due to simply retaking the test, but potentially due to the exposure to both the dialogue with scientists and to the exposure to the experiment.

Our results illustrate how incorporating hands-on derived knowledge into the classroom can produce a significant improvement of students' knowledge of the focal subject (Orr, 1992; Songer et al., 2002; McComas, 2004; Jordan et al., 2009). However, when conducting the experiment, it was less clear whether young adolescents would be able to collect scientific data that would be of real value to researchers. In particular, the process of weighing plants required considerable attention to relatively fine-grained measurements and the use of the metric scale—topics that are known to be challenging for middle school students in the United States (Slavin and Lake, 2008). In addition, the activity was sensitive to the successful completion of multiple sequential steps: students had to bring soils in both plants and soil pots to field capacity, weigh the pots, record the values in decimal format to the second decimal place, and then enter the data into the workbook on the smart board. Processes that involve multiple steps are often prone to error, especially with relatively young participants (Michaels et al., 2008; Hassard and Diaz, 2008). Nonetheless, during the week-long experiment there was little off-task or disruptive behavior, and, notably, a peer-review-type culture was developed in the classroom, where students would supervise each others' measurements and data transfer to the computer. This peer-interaction constitutes a self-directed data quality control and validation that is useful not only for the students' learning of the scientific process, but also for the accuracy and quality of the data used by scientists.

Although students' reactions to the activity were not formally evaluated, their focused behavior and spontaneous comments suggested that they found the research experience to be highly engaging and motivating. Through informal classroom conversations with the students and their teachers, we received feedback that the spatial layout of the spreadsheet designed for data entry enhanced student understanding of the relationships between the data values. The use of the smart board technology (SMART Board by SMART Technologies) was also a contributor to student engagement in the activity. We observed that students were engaged in guaranteeing the correctness of their measurements. Having the values displayed publicly in an easy-to-read fashion led to interesting classroom discussion. This promoted an informal peer review–like process in which the students corrected errors immediately during the data collection and analysis phases of the project.

Even though the mathematical concepts included in the assessments were designed to evaluate simple arithmetic operations, students were exposed to the concept of non-linear responses (which are very frequent in ecology). When students compared their results to the linear-response hypothesis in the discussion of results session, many of them seemed to have understood the concept and grasped the importance of considering non-linear responses when analyzing environmental (ecological) processes. Finally, students were engaged by the immediate feedback the spreadsheet calculations provided, expressing their interest in analyzing the immediate graphic update as values were entered.

It is likely that the presence of the university researchers in the classroom helped to support the success of the experiment. In addition, the two participating science teachers were experienced middle school instructors who were skilled in classroom management. Although specific knowledge associated with the concepts of evapotranspiration can be delivered by targeted instruction, we believe that the overall experience, including interaction with scientists, hands-on experimentation, data generation and analysis, and discussion with peers and scientists about data and results together add another level of learning and understanding that goes beyond targeted instruction alone and improve the potential for learning, as suggested by the results of our pre- and post-experiment assessments. Further research is required to evaluate the degree to which activities like the one we present here can be implemented without the physical presence of the researchers or with less experienced teachers.

The data generated by the four sub-groups in this experiment, which was consistent with the hypothesized relationship between vegetation cover and the partitioning of evapotranspiration, have been directly used to increase the breadth of experimental results of the larger scale Biosphere 2 study and have led to the development of a new hypothetical framework that discusses a broader range of responses of ET partitioning to vegetation cover than presented in previous hypotheses: the predominance of a suppression effect on soil evaporation, a suppression effect on transpiration, or a combination of both, associated in response to vegetation and climatic characteristics (Villegas et al., 2009b). Notably, our results illustrate how educational experiences can be also used as "citizen science" opportunities, where non-scientists can collect data and contribute to relevant ecological research while gaining an enhanced relationship with their community and with nature. Although not formally recorded or evaluated in our instruments, the fact that students were constantly reminded that they were participating in a larger scientific effort seemed to have generated a lot of enthusiasm in the groups, which is a fundamental element in citizen-science projects (Evans et al., 2001; Cohn, 2008; Bonney et al., 2009; Silvertown, 2009). Further, our project was successful not only in translating relevant scientific research into the classroom, providing students with hands-on experience through active participation in an experiment, but also in informing students how to better communicate their results both to their peers as well as other people in the classroom (Roth and Lee, 2004; Trumbull et al., 2000; Baumgartner et al., 2006). This model may not work for all kinds of scientific enquiry because it requires that the subject of the scientific investigation can be successfully translated into classroom activities.

In summary, our results illustrate that the incorporation of experimental knowledge supported by data management tools can constitute a key instrument in successful delivery and understanding of scientific information in the classroom. Our classroom activity demonstrates how current scientific research can be effectively incorporated into the science curriculum, which in turn can be used as an instrumental tool to produce scientifically-relevant data that can benefit both educational processes as well as the advance of natural sciences.

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Appendix A: Pre- and Post Assessment Instrument

Evapotranspiration Project

Name: ____________________________________ Date: _____________ Time: _____________

Teacher: _________________________

NOTE: if you don't know the answer, just leave it blank.

(1) Fill in the Blanks:

Evapotranspiration is ________________ from the sum of ____________________ plus ____________________.

(2) True or False (circle your answer):

Temperature affects evapotranspiration.	(True)	(False)
Humidity affects evapotranspiration.	(True)	(False)
Evapotranspiration is the same as condensation.	(True)	(False)
Plants have nothing to do with evapotranspiration.	(True)	(False)

(3) Choose the correct answer:

Evapotranspiration is an essential component of:

(a) The Water Cycle (b) the Vegetable Cycle (c) the Economic Cycle
(d) All of the Above (e) None of the Above

Evapotranspiration is found in:

(a) Outer Space (b) The Rainforest (c) The Desert
(d) Answers (b) and (c) (e) All of the Above

To study evapotranspiration I will need:

(a) Soil (b) Sun (c) Water
(d) All of the Above (e) Answers (a) and (c)

(4) At noon, just before lunch, John weighed himself and found he was 78 pounds. After lunch, his friend Jane asked him how much the food he ate weighed. How can John and Jane figure out how much the food he ate weighed? (Only a short answer is needed.)

(5) There are about 28.35 grams in 1 ounce. There are 16 ounces in 1 pound. How many grams are in one pound?

(6) John is a teenager. He wants to find out how much he weighs. Three scales are available: (a) measures from 0 to 1600 grams, (b) measure 0 to 250 ounces, and (c) measures 0 to 250 kilograms. Which scale is the best one to use? (Circle one.)

(a) Scale a (b) Scale b (c) Scale c
(d) None of the above

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