Searching for “Preparation for Future Learning” in Physics

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Abstract. “Preparation for future learning” is a term describing a new approach to transfer. In addition to focusing on learning environments that help students better apply developed knowledge in new situations; education researchers are searching for educational interventions that better prepare students to learn new information. The pioneering studies in this field were conducted by J. Branford and D. Schwartz in psychology and mathematics, specifically in the area of statistics. They found that students who engaged in innovation before being exposed to new material, learned better. We attempted to replicate their experiments in the field of physics, specifically in the area of conductivity. Using two experimental conditions and one control, we compared student learning of thermal and electrical conductivity from a written text. We present the results of groups' performance on seven qualitative questions after their learning in this area. [Supported by NSF grant DRL0241078]

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INTRODUCTION

The instructional goals for introductory physics courses are more extensive and demanding now than in the past. As scientific knowledge increases at a pace never before seen, the extent of content makes it impossible for students to learn it all in the classroom. Thus one of the goals of instruction should be to help students learn to learn on their own [1].

Studies in learning and transfer provide indications of the types of learning experiences and the ways of sequencing them that make students' learning of the new content on their own more effective. Students learn more when, prior to encountering the normative answers in a lecture or a text, they work on producing their own solutions [2, 3]. In this paper we describe a study that investigates what types of learning experiences in physics labs lead to student's better learning of new physics concepts on their own.

THEORETICAL FOUNDATION

Traditionally, researchers in education have defined *transfer* as the extent to which a behavior of the past is repeated in new circumstances [4]. As the circumstances are new, the replication of any given behavior is not trivial. People must first realize the applicability of the operation to the new situation and then they have to adapt it to the new circumstances. Researchers have disagreed on whether such transfer occurs: some consider transfer to be very scarce and others all-pervading [5]. More recently, expanded understandings of the phenomenon of transfer have started to emerge [6]. “Preparation for future learning” (PFL) is one such view developed by Bransford and Schwartz [7] who suggested that the different experimental results can be reconciled by adopting a wider theoretical perspective. Instead of focusing on what individuals “transfer out” to apply in new situations, one should focus on what individuals “transfer in” when facing a new problem [8]. To study and measure this “transfer in”, the authors together with other researchers developed and applied the “double transfer” experimental methodology [2, 9]. In “double transfer” experimental design, two groups receive different instructional treatments and later the same learning resource, which might be for example a follow-up text or lecture, to construct new knowledge. After learning on their own from this new resource (transferring in what they learned during the treatment), all subjects have to solve the same problems by applying the newly developed ideas (transferring out). The PFL literature reports that when students innovate seeking their own solutions for a problem, they start to develop the knowledge needed to make sense of the reading or lecture and thus to perceive its relevant features and to frame the problem productively [3, 8]. The present study follows the “double transfer methodology” and explores what type of instructional lab experiences

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better prepare students to learn in the future.

DESCRIPTION OF THE STUDY

The study took place over two days (Saturday and Sunday, three hours each day) in March of 2009. Participating students were paid volunteers from the second semester of Physics for the Sciences – an algebra-based course for science majors. Most of the students in the course were life science, exercise science, environmental science and Earth science majors (not pre-meds). By the time of the study the course material moved past magnetism; thus students were familiar with mechanics, thermodynamics, electrostatics and DC circuits. However, the concepts of thermal and electrical conductivity were not taught. The course followed the *ISLE* curriculum [10] and students had to design their own experiments in labs guided by scientific abilities rubrics [11].

General set-up: On the first day, students worked on laboratory experiments for 3 hours and the following day they read a specially prepared text and answered questions (this took approximately 3 hours as well). Students were split into three conditions: C (control), CB (cook-book), and IL (innovation lab). Both CB and IL conditions were experimental. Students in condition C did a design lab related to mechanics (the lab was similar to the ones they have been doing in the course). Students in condition CB did a thermal conductivity "cook book" lab and students in IL condition did an innovation lab related to thermal conductivity. During the second day, all groups read the same text that explained thermal conductivity and connected the concept of thermal conductivity to the flow of water and the flow of electric charge. Then, they answered the same questions based on the text (materials are available at http://paer.rutgers.edu/pfl/).

Participants: Fifty seven participants were assigned to 3 conditions through matched random assignment technique. First, the students were divided into three groups - high, middle and low - according to their exam scores. Then one student from each category was randomly assigned to one of the 18 lab teams. Finally, 18 lab teams were randomly assigned into three conditions.

Materials for the study: Materials for the study were devised in September - February of 2008/2009. We chose the concept of conductivity for two reasons: a) thermal conductivity was not covered in the course; and b) the concept of conductivity in general can be applied to any flow process.

We designed three different types of labs but both the reading text and questions to assess students' understanding were common for all three groups. The reading text (8.5 pages) described three analogous phenomena: the flow of a fluid, of thermal energy, and of electric charge. The text focused on the similarities between these three phenomena conceptually and mathematically, i.e. the concept of the flow, the importance of a gradient, of the coefficient that depends on the material, and the properties of the container or a pipe – length and cross sectional area. There were 13 questions that students had to answer after the reading; seven of those questions focused explicitly on the content of the reading (the other 6 are being used for a different study). To ensure face validity of the materials, two experts outside the group reviewed all materials.

Details of the first day of the study: Students in IL condition had to develop by themselves the concept of thermal conductivity and invent a coefficient to quantify this property. We made available to them a variety of experimental apparatuses. Their lab handout did not mention the term and only directed them to invent a physical quantity to describe the difference between Styrofoam and aluminum in terms of their ability to transfer thermal energy.

Students in condition CB worked on traditional lab activities. They had to determine the coefficient of thermal conductivity of the material of a plastic bottle. The handout had a summary of the theory necessary to understand what the coefficient of thermal conductivity is, and a step-by-step method for determining its value experimentally. Basically it was a typical cook-book lab.

Students in condition C had to design an experiment to test the hypothesis whether kinetic energy is constant during the collision of bowling balls. This lab was similar to the labs that students did in the course the content was also familiar and not related to the study. Therefore, only students in CB were told during the first day what the coefficient of thermal conductivity was and how to determine it. Students in conditions C and IL did not see this term and were given no information about it. Students had three hours to work on the labs.

Details of the second day of the study: During the second day all students received the text at the same time and when they finished reading, they received the questions. They were allowed to use the text as a resource to answer the questions. Each student recorded on the answers sheets both the time when she/he started and finished answering the questions.

Collected data: During the first day we collected students' lab reports. During the second day we collected time data and student responses to the questions. In this paper we will only use the data collected during the second day of the study.

FINDINGS

Observations of student behavior during reading and *question answering time:* We recorded the amount of time students spent reading the text and answering the questions. We found that students spent different time answering the questions (means for conditions C, CB, and IL are 104, 99, and 132 min. respectively, F (2, 53) =14.7, p<0.001). To find which conditions were different from each other, we used Bonferroni's method. Post hoc tests indicate that the mean difference between C and IL is -27.9, between CB and IL is -32.8. Both are significant at α = 0.05. The total time on the task was also different (means for C, CB, and IL are 130, 127, and 162 minutes respectively, F (2, 53) =16.7, p<0.001). The mean difference between groups C and IL is -32.2, between CB and IL is -34.7, both significant at α = 0.05. Students in IL spent significantly more total time answering the questions and overall working on the assignment.

Coding of students responses: We developed a coding scheme post hoc to depict in detail the scope of students' answers to the 7 questions that assessed their understanding of the following 5 ideas in the context of conductivity: flow, gradient, coefficient, length, and area (questions is at http://paer.rutgers.edu/pfl/). These were the concepts that students had to understand from the reading that specifically explored the analogy (in terms of these five ideas) among different processes that can be described as flow. We then blindly coded each student's response to each of those 7 questions for an indication of understanding of the appropriate categories. Sometimes we coded a student for one category for the same question multiple times. At the end there were 9 possible instances for a student to have his/her understanding coded for the understanding of the concept of flow (in three problems), 21 for the concept of a gradient (in 4 problems), 4 for the concept of the coefficient of conductivity (either thermal or electrical, in 4 problems), 3 for length (3 problems) and 4 for area (4 problems). When students displayed understanding, its quality was coded on a scale of 0-3 and when a student demonstrated a wrong idea, this was coded with negative codes on a scale of 0-(-2). In some problems there were no negative codes. To establish the reliability after the codes were first developed, a group of 2 researchers scored 10 student responses and subsequently revised the codes until the reliability coefficient kappa reached 0.61 (substantial or almost prefect reliability). For most of the codes the achieved reliability was 0.87 - 1. After the coding was finished, we expressed the codes as a percent of a maximum possible score for each problem, and then we calculated the average score for each problem for each group. The results are presented in Fig. 1, which shows that students in condition IL had the highest average score on 4 of 7 problems, while students in conditions C and CB had the highest score on one problem each.

After determining the average score for each problem, we determined the total score as the sum of the scores on all problems for each student and compared the total scores of the students in the three groups.

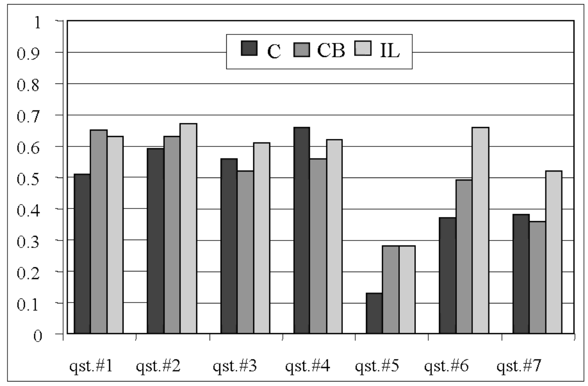

FIGURE 1. Normalized Scores of the Three Conditions

The descriptive statistics are presented in Table 1. Both the mean and the median score of condition IL are higher than the scores of C and CB. The results of ANOVA (F (2, 50) =3.99, p=0.025) show that the three conditions are statistically different. To find which condition is statistically better, we conducted a post-hoc multiple comparison of the groups using Bonferroni's test. The test showed no statistical significance between C and CB, a significant difference between C and IL (IL being significantly better) and a marginal statistical difference between CB and IL, IL being better (Table 2).

TABLE 1. Total normalized scores

	C	CB	IL
Mean	3.2	3.45	3.98
S.D.	0.78	0.74	0.96
Median	3.25	3.45	4.05

TABLE 2. Post hoc comparisons (Bonferroni's test)

Cond.	Cond.	Mean Differ.	Std. Error	Sig.
C	CB	-0.25	0.28	1
C	IL	**-0.78**	**0.28**	**0.02***
CB	IL	-0.53	0.28	0.19

DISCUSSION

The results of this study indicate that instructional labs can facilitate students' construction of physics concepts. Even though many instructors regard laboratories as an essential part of learning physics, the literature is not unanimous on this issue, questioning the usefulness of the labs for non-physics majors [12] and for high and low achieving students

[13]. Our results show that laboratory tasks affect students' development of physics concepts: there are statistically significant differences in the learning among the groups that represented students of all achievement levels engaged in the different tasks.

We believe that we could capture the learning in the lab because of the method of assessment we used and the type of the lab in which students engaged.

Assessment: Research has shown that traditional recall or problem solving tests are incapable to uncover the deep understanding that is necessary for the construction of knowledge which can be "transferred in" to make sense of a phenomenon [9]. To evaluate the aptness for learning, we must use dynamic assessments, when learning takes place during the testing procedure [14]. Such assessments reveal which instructional activities facilitate learning and most importantly, it evaluates learners' ability to learn (the first and principal goal of instruction). We assessed students' ability to learn from a written text.

Lab tasks: With respect to characteristics of the laboratory assignments, it is reasonable to assume that not all the tasks that students can complete in a lab are equally productive. Thus, if students are solely required to follow directions, probably they will improve in their ability to follow directions as a consequence. However, as we found, when students invent their own solutions to a relevant problem, they are capable of later learning better from a given resource. There is a statistically significant difference in students' learning from a common text between the individuals in the "innovation" condition IL, and those in C, who did not have any experience with conductivity in the laboratory; students in IL learned more. At the same time we found no significant difference between the students in condition C and the students in condition CB, who completed a cook-book lab type assignment on thermal conductivity. Finally there is a marginally significant difference between students in IL and CB in favor of IL. Although this last difference is just marginal, we believe that the results could indicate the value of student original "innovation" for learning in subsequent activities. One of the downsides of the study is the small size of the samples. The findings are consistent with the outcomes of multiple studies on PFL [2, 3, 9] as well as previous PER studies, which have shown that when students invent their own physics representations, they develop a deeper understanding [15]. The literature on preparation for future learning attributes the effects of innovation to the fact that students become aware of the relevant features of the problem and develop a differentiated knowledge base [8]. In addition it is possible that through innovation, students may come to really understand the questions that get answered in lectures and textbooks.

We found that IL students spent significantly more time reading the text and answering the questions than students in the other conditions. It is possible that that students' original struggle with the material increased their motivation. By pursuing their own solutions, students may internalize the questions and, as a consequence, became more interested and more receptive to the canonical solutions.

Some may argue that the effect of the lab assignments could be explained in terms of the amount of time that students spent on task. Although we cannot rule out this hypothesis solely from the design and findings of this present study, we may discard it if we situate our investigation in the whole body of research on preparation for future learning. The effectiveness of different activities in getting students ready for learning goes further than the amount of time that students are kept busy [2].

The findings of this study are promising as they point toward new, more effective ways of using laboratory instruction in physics education.

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