

From Physics to Biology: Helping Students Attain All-Terrain Knowledge

Maria Ruibal-Villasenor*, Eugenia Etkina*, Anna Karelina*, David Rosengrant*,
Rebecca Jordan[†] and Alan Van Heuvelen*

*Graduate School of Education, Rutgers University, New Brunswick, NJ 08901

[†]Ecology, Evolution and Natural Resources Department, Rutgers University, New Brunswick, NJ 08901

Abstract. This paper is the third in a series of three describing a controlled study “Transfer of scientific abilities”. The study was conducted in a large-enrollment introductory physics course taught via Investigative Science Learning Environment. Its goal was to find whether designing their own experiments in labs affects students’ approaches to experimental problem solving in new areas of physics and in biology and their learning of physics concepts. The part of the project presented in this paper involves students in the experimental and control groups solving a biology-related problem that required designing an experiment and evaluating the findings. We found that students who were in the sections where they had to design their own experiments during the semester were able to transfer the abilities they acquired in physics laboratories to solve a novel biology problem. The project was supported by NSF grant DRL 0241078.

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INTRODUCTION

This manuscript is the third of a series of three papers in these proceedings that describes a study whose goal was to investigate the effects of design labs on student learning of physics and their acquisition and transfer of scientific abilities. The motivation for the study, its theoretical foundations, and its methodology are described in the first paper of the series: “Spending time on design: does it hurt physics learning?” The second paper described the “physics” transfer experiment in which students had to solve an experimental problem in an area of physics that they had not studied before. This paper describes a transfer experiment in biology.

The experiments were conducted in a large enrollment algebra-based physics course (with an integrated lab) for science majors. The purpose of these experiments was to test the *hypothesis* that students that learn in a educational environment that resembles scientific inquiry who design their own experiments in a physics lab not only can learn as much physics content as those students who follow the directions in guided write-ups, but also can acquire and transfer scientific abilities better than their counterparts. The *independent variable* in this

experiment was the type of learning experiences that the subjects encountered in the lab: they had to complete assignments that were similar in terms of the physics involved but very different in nature. In addition they did not receive the same type of feedback from the TA’s. Excluding the laboratories, every one of the participants experienced the same learning environments and worked on the same tasks: the students attended the same large-room meetings and recitations which followed *ISLE* curriculum [1]. The *dependent variable* in this experiment was the extent of student learning and transfer revealed in their performance on the exams and on special experimental tasks. This was measured by exams grades, the coding of lab reports using “scientific abilities” rubrics and the amount of time that students spent on different activities during the labs.

In order to make the comparisons possible, we split the course lab sections into two groups of equal size (about 90 students in each, the number varied slightly during the semester). The students in the treatment group (called design group) designed their own experiments and composed sophisticated lab reports in which they described and explained their experimental procedure, evaluated experimental uncertainties, justified theoretical assumptions, etc. The students in

the control group (non-design students) performed the same experiments but were guided by the directions in lab write-ups. The assumptions instructions for evaluating the uncertainties were provided for them. In contrast, the students in the design group had to struggle and find the answers with thoughtful efforts similar to scientists doing research [2].

The research question in this paper is whether the students who during one semester design their own experiments and are compelled to concentrate on the elements of the scientific investigation, acquire and are able to transfer scientific abilities to a different subject matter better than those students who perform similar lab exercises but do not design their own experiments. This portion of the study focuses on transfer between two different scientific contents (physics and biology) but the same lab environment [3]. Therefore the contexts of the learning tasks and transfer task are very similar but the content differs.

METHODOLOGY

A biology task was given as the final lab exam for the course, for this reason all the students completed the task. Both the treatment and the control groups had to design an experiment to find the transpiration rate of a certain species of plant and subsequently to write a report detailing their experimental procedures, calculations and conclusions. The exact text of the assignment is in the appendix. The researchers selected this lab problem because: a) measuring transpiration is a task simple enough to complete for students with very little plant physiology background; b) students can use multiple measures to determine transpiration rates which gave them some room for inventiveness, evaluation and decision making; and c) students are more willing to accept a biology assignment as a final exam for their physics lab if they perceive that there is a physical basis (evaporation and osmosis) underlying the biological process of transpiration. This last feature of the task as well as the similarity of the contexts may have facilitated the transfer of scientific abilities.

In "Resources for the practical", the handouts provided definitions of transpiration and humidity and also included a table with saturated vapor density or water as a function of temperature (the course did not cover humidity at all). In addition, the students could consult the internet.

During the practical exam students in each lab section worked in the same group of three or four as they did during the semester. During the exam as during the semester, students submitted individual reports for grading. The four treatment sections had the exam earlier in the week than the control sections.

We assessed the extent of transfer that took place between the physics laboratories and the bio task by a) observing students' behavior during the completion of the task and b) analyzing students' lab reports. During the transfer task an observer trained in the method described by Karelina and Etkina [4] measured and recorded the amount time that a group of students from each lab section spent on different behavior patterns. We examined students' reports to find patterns in their length, content and style. In addition we evaluated the quality of the reports using the "scientific abilities rubrics" [5]. All rubrics that we used for scoring can be found at <http://paer.rutgersedu/scientificabilities>.

FINDINGS

Students' behavioral patterns:

The teams of "design students" spent more time completing the same transfer task than the teams of "non-design students". It took an average of 23.5 minutes more for the design team to finish their reports. However this difference (176 ± 26 min and 153 ± 26 min) is not statistically significant ($p=0.1221$).

Figure 1 shows the average amount of time that four randomly selected teams from each group spent on six different categories of activities.

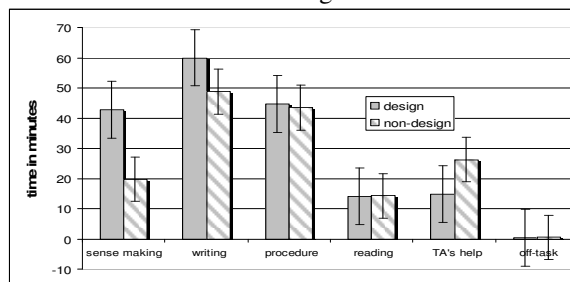


FIGURE 1. The time spent on different activities by teams of students during the final lab exam (biology task).

There is a significant difference ($p=0.0026$) between the time duration that the subjects spent on sense making. It was 42.75 ± 9.84 minutes for design teams and 19.75 ± 4.50 minutes for non-design teams. In addition, design students spent more time writing their reports and less time receiving help from the TA; however the differences were not significant ($p=0.166$ and $p=0.061$ respectively).

Differences in lab reports:

In addition to the differences in the amount of time that the two groups spent on sense making, we found differences in the quality of students' lab reports. Non-design students' reports tended to be shorter on average. They included fewer detailed descriptions of the procedures and fewer pictures and diagrams. Moreover, the reports of non-design students rarely

contained any explanations of the advantages and limitations of the methods used, or any justifications for the choice of the approaches and procedures. In order to compare the labs reports from students in the two groups, we used the “scientific abilities rubrics” devised and validated in multiple studies [5] to evaluate students’ written lab reports. A rubric describes four levels of performance for a particular ability (0 to 3) and assigns each level a particular score. “0” means missing; “1” – inadequate; “2” – needs improvement; and “3” – adequate. We established the ratings for the sample lab reports with a biology expert and then checked the inter-rater reliability and test-retest reliability of the scoring with two raters and by rescoreing some part of the lab reports. The ICC (intraclass correlation) coefficient was different for different rubrics but always higher than 0.85, which shows an acceptable raters reliability.

Identifying assumptions and evaluating their effects: 91% of the non-design students showed no evidence that they had tried to identify the assumptions implicit in their procedure and calculations. Only 6% of the design students were in the same group. We used two rubrics “the ability to identify assumptions” and “the ability to determine specifically the way in which assumptions affect the results” to score two different experiments that students described in the reports. In order to compare the two groups we added the four scores (two per each experiment) and analyzed this aggregate score statistically. [We followed similar procedures when studying the students’ abilities to analyze and minimize experimental uncertainties and their abilities to represent and analyze data.] The difference between the two groups was statistically significant (fig. 2). More than half of the design students (53.3%) tried to evaluate the effects of the assumptions that they made on the result or they actually validated their assumptions. Not a single student in non-design group even attempted to do this.

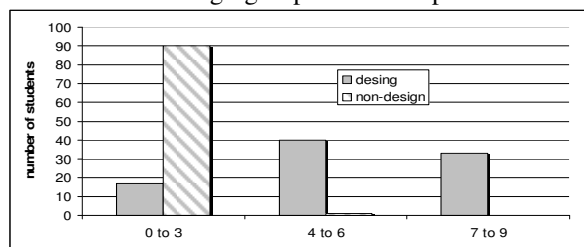


FIGURE 2. The number of students whose reports received aggregate scores for the ability to identify assumptions and the ability to determine the effects of assumptions binned in three categories. The maximum aggregate score that was possible was 12.(Chi-square=119.9, $p < 0.001$)

Identifying, evaluating and minimizing uncertainties: Both groups of students had to evaluate uncertainties

during the semester labs. However, the design group had first to identify the uncertainties, evaluate them, and then to figure out how to minimize them. The instructions in the write-ups in non-design labs included the descriptions of the sources of uncertainty and the minimizing procedures. During the bio practical lab 83.3% of the design students were able to identify correctly most of the uncertainties; 75% of non-design students did not identify any of them.

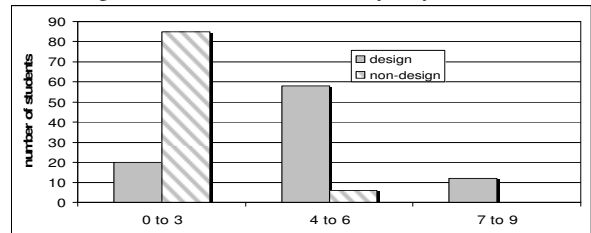


FIGURE 3. The number of students whose reports received aggregate scores for the abilities to identify, evaluate and minimize the effect of uncertainties binned in three categories. The maximum aggregate score was 9. The difference is statistically significant (chi-square=94.49, $p < 0.001$).

Evaluating the result by means of an independent method: When conducting experiments to solve experimental problems during the semester, students in both groups were taught that it was important to perform two independent experiments, to compare the results using experimental uncertainties, and to discuss the possible reasons for the difference. However, only 5.4% of the non-design students evaluated correctly the results including a discussion that referred to both uncertainties and assumptions, while 39% of design students did. Figure 4 presents the results of the scoring of lab reports for this ability.

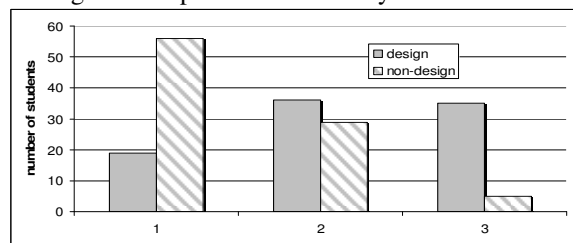


FIGURE 4. The number of students who received scores from 1-3 for the ability to evaluate the result by means of an independent method (nobody received a 0 as the task specifically asked to design two experiments). (Chi-square=42.25, $p < 0.001$).

Recording, representing and analyzing data appropriately: These are central abilities for conducting almost any type of research. Most of the lab reports from both groups received scores of 2 and 3 on this ability for the two experiments. However, design students received a perfect or almost perfect score twice as often as non-design students.

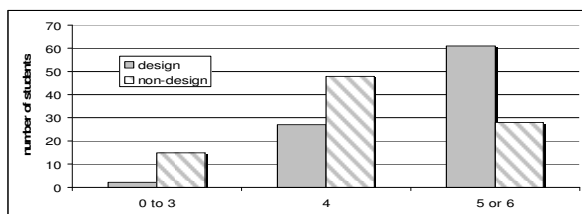


FIGURE 5. The number of students who received scores from 0-6 for the ability to record, represent and analyze data (aggregated for two experiments). The two groups are significantly different (chi-square=28.05, $p < 0.001$).

Communication: This is not a minor ability. Scientists need to be able to communicate their ideas to the other members of the scientific community as well as to the general public. Thus, teaching science involves training students to communicate: to explain their choices, describe completely the procedures, and include good pictures and diagrams. The statistical analysis of student scores on this ability shows that 56% of the non-design students had serious problems describing their experiments while only 17% of the design students did (fig. 6).

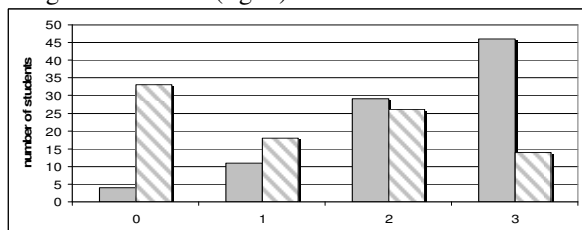


FIGURE 6. The number of students who received scores from 0 to 3 for the ability to communicate scientific ideas. (Chi-square=41.645, $p < 0.001$).

DISCUSSION

The study reported in this paper shows that students who design their own experiments in a physics lab and engage in activities that focus their attention on the elements of scientific investigation, acquire scientific abilities and are able to transfer them to a new content area better than students that follow directions in write ups. Both the learning tasks and the transfer task took place in a very similar context: the same course and the same room but weekly laboratory investigations as opposed to the lab exam.

We found that design students were significantly better than non-design students in the ability to identify assumptions and evaluate their effects; the ability to identify the sources of, evaluate the effects of, and minimize uncertainties; the ability to record and analyze data; and the ability to communicate. These abilities were measured by scoring students' lab reports using the "scientific abilities" rubrics.

Design students spent more time on sense-making (an average of 23min more than non-design students).

That is probably why the reports of design students reflected a more thoughtful take on the task, as they contained more explanations, evaluations, and justifications of the procedures that students selected.

The above results seem to indicate that the design of experiments promotes a more profound and meaningful approach toward laboratory investigations in a particular physics course and possibly in science in general. This new approach promotes in turn the transfer of scientific abilities because students understand their purpose. For instance, uncertainties are not fastidious drill exercises at the end of every experiment but are instead a requisite needed to arrive at well-founded conclusions.

The results of this study have a special relevance since introductory science should *introduce* the practices the scientific community to students. Students need to assimilate the language, methods and quality standards of scientists. The goal of introductory physics courses must be not only to facilitate the learning of physics concepts and their relationships but, equally important, to teach the process and nature of physics through the students' actual practice of the scientific inquiry.

APPENDIX

Application experiment, transpiration rate:

Conduct two experiments to determine transpiration rate using stem cuttings from a single species of plant. *Available equipment:* water, beaker holding plant cuttings, parafilm, tubing, ring stand, graduated pipette, timers, humidity sensor, cup, cup with hole, scissors, and two droppers.

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