Design And Non-design Labs: Does Transfer Occur?

A. Karelina, Eugenia Etkina, Maria Ruibal-Villasenor, David Rosengrant, Alan Van Heuvelen, and Cindy Hmelo-Silver

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

Abstract. This paper is the second in the 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. This paper reports on the part of the study that assesses student work while solving an experimental problem in a physics content area not studied in class. For a quantitative evaluation of students' abilities, we used scientific abilities rubrics. We studied the students' lab reports and answers to non-traditional exam problems related to the lab. We evaluated their performance and compared it with the performance of a control group that had the same course but enrolled in non-design labs instead of design labs. The project was supported by NSF grant DRL 0241078.

Keywords: Design labs; transfer, sense-making, scientific abilities.

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INTRODUCTION

This manuscript is the second 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, the theoretical foundation, and the set-up are described in detail in the paper "Spending time on design: does it hurt physics learning". The experiment was conducted in an introductory physics course for science majors of about 180 students. The number of students varied slightly during the semester. The students attended the same large room meetings and recitations taught via the Investigative Science Learning Environment (*ISLE*, [1]). In the labs they were randomly split into two equal in size groups. In the experimental lab sections ("design students") students designed their own experiments, wrote elaborate lab reports in which they described and explained their experimental procedure, evaluated experimental uncertainties, justified theoretical assumptions, etc. [2] Students in the control lab sections ("non-design" students) performed the same experiments but were guided by the directions in the lab write-up. The assumptions were provided for them, and instructions for evaluating uncertainties were provided.

LAB TASK

To assess how students transfer scientific abilities to an unfamiliar physics content in the same functional context (classification by Barnett and Ceci, [3]), we developed a lab task where both groups designed an experiment and wrote a lab report. In contrast to regular labs which students performed during semester this particular task was identical for the experimental and the control groups. The task involved drag force in fluid dynamics. This physics content was not covered in the course. To minimize the spreading of information among the students we developed four similar versions (Appendix). Students were provided some necessary and some redundant information in the write-up and had access to textbooks and the internet.

The students performed this task during the lab (3 hours) on week 13 of the semester. Prior to this, they performed 10 regular labs, different for the experimental and control groups and described in details in the first paper of the series. The lab sections were spread from Wednesday to Friday. Four experimental sections had labs on Wednesday and Thursday morning; control sections had the lab on Thursday afternoon and Friday morning. The drag force lab was attended by 89 students in each group.

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STUDY METHODS

To assess and compare performance of the experimental and control groups we used different methods. One was direct observation of students' activities during the labs. The second was a general impression of students' lab reports. Based on the impression we decided how to code our observations for quantitative analysis. For this we used some of the scientific abilities rubrics developed earlier [4].

To monitor students' activity, a member of our group observed student behavior during the lab (one group from each lab section—eight groups total). The observer timed and recorded all student activities and conversations and later coded his observations using a coding scheme described in [5]. This coding scheme groups all students' activities into several categories: sense-making, writing, procedure, reading, TA's help, and off-task. The reliability of this method was established prior to the study.

To compare the lab reports of the two groups we chose the following abilities: to communicate, to analyze data, to evaluate assumptions, and to evaluate the result by a second method. We did not evaluate the ability to design a reliable experiment as we observed students exchanging information as the week progressed. Thus we suspected that later sections gained an advantage over the earlier groups.

We used students' written lab reports to evaluate the above abilities using the rubrics devised and validated in multiple studies [4]. 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 checked the inter-rater reliability and test-retest reliability of the scoring with several different raters and by rescoring some part of the lab reports. The ICC (intraclass correlation) coefficient was different for different rubrics but always higher than 0.89, which shows an acceptable raters reliability.

FINDINGS

Observation of student behavior: The observations showed that there was a remarkable difference in the behavior of design and non-design students during the drag force lab. First we noticed that the lab took significantly more time for design students. Although the lab tasks were the same, the design groups spent 40 minutes more time in lab room then non-design students. The difference between the lab duration (162±17 min and 120±25 min) is statistically significant (p = 0.038). Figure 1 shows that the main contribution to this difference came from time spent on sense-making discussions. The sense-making lasted about 52±10 minutes in design groups and only 15±5 minutes in non-design groups. This difference is statistically significant with the level of significance p = 0.0007. The time students spent on other activities was about the same for both groups. There was a slight difference in the time for writing and TA's help but based on our data we cannot say that this difference is significant.

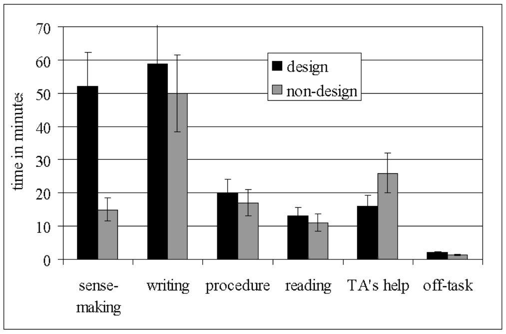

FIGURE 1. The time spent on different activities by students of design and non-design sections. The averaging was over four groups of each type.

General impression: The difference was not only in the time spent on the task. The quality of work was also different. Below we show two examples of the lab reports of two groups of students: one of the best non-design groups and one of the best design groups.

Non-design lab report (Task: version 2)

Determine the velocity of the balloon when air resistance and gravitational force are equal

- place the motion detector on a stand
- place the sensor face downward
- place the helium balloon on the floor
- release the balloon as the motion detector collects data
- on the position-time graph find constant slope segment
- repeat twice more
- find the average velocity
- …determine Reynolds number. You should get a value larger than 10.
- use the equation to solve for drag coefficient …Cd=0.51
- now repeat this procedure for air filled balloon. Make sure to drop the balloon from the level of the motion detector…
- air filled balloon - Cd= 0.61

Drag coefficient for air and helium are indeed different.

Design lab report (Task: version 4)

Part I. We need to know which equation to use based on the Reynolds number…To find the velocity we will have a motion sensor above the helium balloon. The balloon will be released and the motion sensor will measure its upward velocity. *Here is picture of the set-up. The chart is attached*

The velocity was taken 3 times and averaged to allow for random uncertainty....

When the balloon is let go the velocity increases until it reaches terminal velocity, here the net force is zero and acceleration is zero.

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When balloon is at rest the net force on it is equal to zero too. *Here are two free body diagrams for balloon at rest and at terminal velocity.* The buoyant force is always the same. Therefore the drag force is equal to the force of the string attaching the balloon to the scale… $Cd = 0.43$

Assumptions: balloon travels in straight path, balloon is point particle, cross-section is circle, cross-section is level. *Uncertainties are evaluated: diameter, scale, motion detector and random uncertainty of the velocity.*

Part II. Prediction (*of the speed of the air balloon falling to the ground*)

When the air balloon falls it reaches terminal velocity drag force equals the force of the earth. *Here are two free body diagrams for balloon at rest and at terminal velocity* … We can use the equation … to get the velocity: $V= 0.438\pm0.021$m/s *(the final result incorporates uncertainty)*

We will have a motion sensor aimed down and drop a balloon below it. It will record the velocity of the air balloon before it hits the ground. *Picture is here.*

Assumptions: 1. Balloon achieves terminal velocity – otherwise $Fe \neq Fd$; 2. $Re>10$ – otherwise Fd equation is wrong 3. Cd is the same for air and helium – otherwise calculated velocity will be wrong.

V was measured and averaged over 3 trials (1.476, 1.02, 1.153). $V=1.216\pm0.228$m/s

The values do not overlap and therefore are not equal. Some assumptions must have been incorrect.

Scientific abilities rubrics: The reading lab reports reveals the features that make difference in the performance of two groups. The quantitative analysis of the lab reports supported the general impression on students' performance. Figures 2-5 show that there are significant differences in the lab reports of design students and non-design students. Design students demonstrated significantly better scientific abilities than the non-design students.

Evaluating the effect of assumptions: Figure 2 shows that 57 design students (more then 60%) got score 2 or 3 that is they identified relevant and significant assumptions of the theoretical model that they used, whereas only a few non-design students did. Most design students who identified assumptions also evaluated their effect on the result or validated them. Not a single student in non-design section made an attempt to do this.

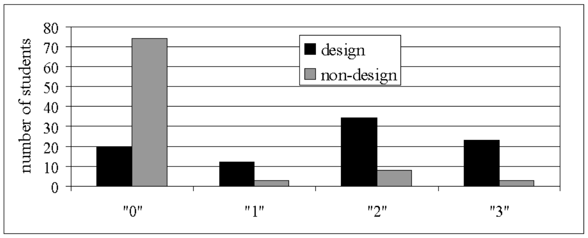

FIGURE 2. Ability to consider assumptions in the theoretical model. The difference is statistically significant with chi-square = 68, $p < 0.001$.

Evaluating effect of uncertainties: During the semester non-design students learned how to identify sources of uncertainties and how to evaluate their effect on the final answer. But only 11 of them (12%) got score 2 or 3 and transferred this skill in the independent experimental investigation (Fig. 3). More then 50% of design students evaluated the effect of experimental uncertainties in this lab.

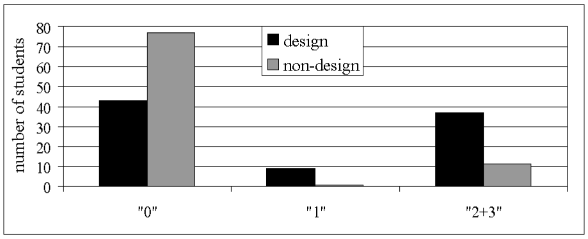

FIGURE 3. Ability to evaluate the effect of uncertainties. Chi-square = 30, $p<0.001$.

Evaluating the result by means of an independent method. A high score on this rubric is possible only when a student discusses the discrepancy between the results of two methods and possible reasons of this discrepancy considering assumptions and uncertainty. As a result design students demonstrated a higher ability to evaluate the result (see Fig 4). We can see that about 64 of design students (72%) got score 2 or 3, i.e. discussed the reasons for the discrepancy while in non-design sections only 38 students (43%) did.

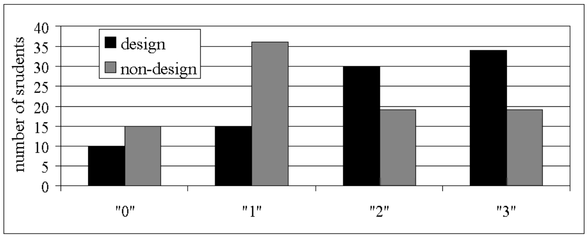

FIGURE 4. Ability to evaluate the result by means of an independent method. Chi-square = 16, $p < 0.001$

Communication: One of the main scientific abilities we want students to develop is an ability to communicate their ideas. This ability includes an ability to draw diagrams and pictures, describe details of the procedure, and to explain the methods. The analysis of lab reports shows that more then 60% of design students drew a picture while only 8% of non-design students did. Figure 5 shows the results of the scoring of the reports using the communication rubric. The difference in their scores is statistically significant (chi-square = 60.6, $p<0.001$).

Understanding of physics: The analysis of the lab reports revealed another interesting feature. Students from different sections demonstrated a different quality of drawing free-body diagrams in spite of the

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fact that during the semester all students learned to draw FBDs the same way.

In this lab about 22% of non-design students draw incorrect FBDs, (i.e. mislabeled or not labeled force vectors, wrong directions, extra incorrect vectors present, or vectors missing), while only 2% of design students made a mistake in FBDs. This difference is statistically significant (Chi-square = 18, p<0.001).

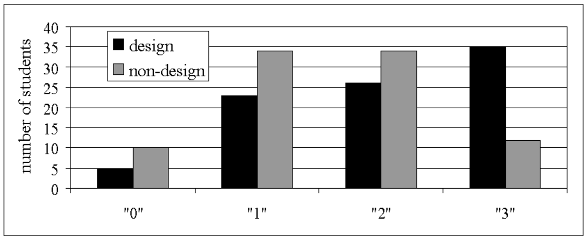

FIGURE 5. Ability to communicate ideas.

In addition, we analyzed the consistency of different representations in student work (free body diagram versus mathematics, a picture versus a free body diagram, etc). We found a difference in the number of students who created inconsistent representations: 22% of design students versus 44% of non-design students ($p<0.025$, chi-square = 7.8).

DISCUSSION

Our studies demonstrated a rather high level of transfer of several scientific abilities in the experimental group, supposedly caused by differences in the performance of the two groups in their weekly laboratory work.

Students who were used to designing their own experiments spent much more time on sense making than the students who were used to following clear instructions. That probably resulted in the more profound investigations and more sophisticated lab reports of design students comparing to control group. The observations of the students during the semester showed that on average design students spent 37 min on sense making versus 14 of non-design students.

We found that non-design students' reports resembled their lab write-ups. They gave step-by-step instructions with scarce explanations, rarely showed their reasoning, and did not try to justify the validity of their methods and procedures. Design students tried to satisfy the usual lab requirements: they described the procedure, drew pictures, explained the reasoning, analyzed data, and evaluated results.

The quality of FBD and the level of representation consistency indicate that design students paid more attention to physics understanding and logical reasoning during the lab than non-design students. One explanation is that during the semester, design students had to reconcile different aspects of the phenomenon and had to make sense of their activity more often then non-design students. That could lead to the higher scores on the rubric evaluating the ability to communicate.

Design students significantly outperformed non-design students in other scientific abilities such as the abilities to analyze data and the ability to identify theoretical assumptions. During the semester design students learned that it was impossible to evaluate the results of their investigations adequately without considering assumptions and uncertainties. The non-design students did not consider evaluating the uncertainties as an important part of the lab, although it was a routine procedure during the semester.

In summary, we found if students consciously plan, monitor, evaluate and reflect on their actions, transfer occurs.

APPENDIX

Complete text of the lab task: Investigation of the behavior of the balloon

Equipment available: *a balloon filled with helium, a balloon filled with air, meter stick, measuring tape, stop watch, motion detector, computer, additional resources.*

Version 1: You hold an air balloon and a helium balloon. Design experiments to determine which physical model best explains their motion if you release them: the model with no air friction, the model with viscous flow or the model with turbulent flow.

Version 2: Design an experiment to determine whether a helium-filled balloon and an air-filled balloon have the same drag coefficients.

Version 3: Use the air balloon to determine its drag coefficient. Then predict the speed of the helium balloon when it reaches the ceiling.

In your report describe the experiment, your analysis and judgment so that a person who did not see you perform the experiment could understand what you did and follow your reasoning. For help we provided some resources on the next two pages of this write-up. You can also use the textbooks available on the instructor's desk or the internet for help.

REFERENCES

1. E. Etkina, & A. Van Heuvelen, Proceedings of *PERC* (Rochester, NY: PERC publishing, 2001, p. 17-21).
2. E. Etkina, S. Murthy, & X. Zou, *AJP*, **74**, 979(2006).
3. S. M. Barnett, and S. J. Ceci, *Psychological Bulletin*, 128 (4), 612-637, (2002).
4. E. Etkina, A. Van Heuvelen, S. White-Brahmia, D. T. Brookes, M. Gentile, S. Murthy, D. Rosengrant, and A. Warren. *Phys Rev. ST Phys, Ed. Res.* **2**, 020103 (2006).
5. A. Karelina, & E. Etkina. In *2006 Physics Education Research Conference*, (Syracuse, NY, July 2006) edited by L. McCullough, L. Hsu, and P. Heron, AIP Conference Proceedings, Vol. 883, 93-96, 2007.

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