

Research Projects In Introductory Physics: Impacts On Student Learning

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Abstract. Over the last two years UBC has completely revamped their introductory course for non-physics majors to present physics in terms of everyday situations and to reinforce connections between classroom physics and real-world phenomena throughout the course. One of the key changes was the incorporation of a final project where groups of students research and present on a topic of their choice related to the course. Students were asked to quantitatively model a real-world situation to make a choice or settle a dispute. At the midpoint and end of the 2008 course students were surveyed with a single transfer problem that tested students' ability to apply physics concepts in real-world contexts. The post-test showed students were more likely to engage in simple (rate)*(time) estimates rather than applying more sophisticated physics principles. Implications for instruction and future work are discussed.

Keywords: physics education research, transfer, student research projects

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INTRODUCTION

Over the last decade science educators have paid significant attention to the idea of scientific literacy.[1] Science educators have begun to consider the ways in which students might be encouraged to develop scientific knowledge and reasoning that might support their ability to make legal, financial, and political decisions.

However research on transfer has demonstrated the difficulty of enabling students to recall and apply their science knowledge in novel situations.[2] Research on student attitudes has also shown that students' beliefs about the relevance of physics typically decline during their first introductory physics course[3,4], which may be a barrier to application of physics knowledge outside the classroom.

Recent changes to the University of British Columbia's introductory course for non-physics majors have attempted to improve both students' attitudes towards the relevance of physics and their abilities to transfer their physics knowledge to novel everyday situations. One of the major changes was the introduction of a research project, where groups of students research and present on an environmental issue or question of their choice. This paper will discuss the format of this research project and our measurements of its impact on students' abilities to transfer physics to a novel real-world problem.

BACKGROUND

Physics 100 at UBC is a 13 week algebra-based introductory physics course. It is a large lecture style course that divides 700 students into three sections, each taught by a different instructor. The lecture is supported by mandatory weekly labs and small-group problem-solving sessions. Students in Physics 100 are typically enrolled in science, human kinetics environmental science, or various arts programs, with fewer than 1% intending to major in physics.

In order to present material that would be more meaningful to this non-major population, the Physics 100 course at UBC was substantially revised in 2007 to present introductory physics in a real-world context wherever possible. The content of the course was also adjusted to include topics with strong connections to energy conservation and climate change. For example the concepts of conservation of energy are explored using the context of home heating and the Earth's energy balance. Kinematics is taught in the context of transportation and associated energy consumption and fuel efficiency. These real-world connections are reinforced through weekly problem-solving sessions in which groups of students work on context-rich [5] problems with realistic settings and a plausible motivation for conducting a calculation.

An important change to the course was the incorporation of a final project where students work in

small groups to quantitatively model and estimate an answer to a scientific question and present their results to their peers. Students choose project topics from a list provided by instructors and which were drawn from a magazine article[6] suggesting various actions to reduce energy and greenhouse gas use, and students were asked to quantify the impact of these actions. For example, past projects have addressed the energy and greenhouse gas savings from using LEDs for city lighting and the energy benefits of paying bills online rather than by paper mail. Suggested topics are limited to those that fell within the scope of students' ability to research and understand the topic and students are free to choose topics that were relevant or that interested them.

There is little explicit instruction on the final project built into the course. The final project assignment is introduced and explained to student groups during the weekly problem-solving session in week 7 of the course. Instructors provide an example project and the project marking rubric. The rubric emphasizes explicit discussion of physics but does not explicitly require students to use sophisticated physics models. Final presentations are conducted in weeks 12 and 13 of the course and are assessed by problem solving session instructors and one lecturer.

It was the intention of the course instructors that working on the final project would give students important practice in applying physics principles to real-world situations. This paper discusses our attempt to test how students' ability to transfer physics changed over the course of the final project.

STUDY DESIGN

In order to assess students' transfer a pre-test was administered to students during the final project introduction session and a post-test was administered at the end of the second presentation session. Two problems were used for the pre- and post-tests: Problem A was administered to half of the class as a pre-test, and then these students got Problem B as a post-test. The other half of the students completed Problem B and then A. Both problems dealt with thermal physics in the context of home heating, topics which were discussed in the first half of the course and tested on the midterm. Assignment of students to one of the two test groups was performed randomly by problem-solving section. Thus, all the students in the same section wrote the same test. Students were given 10 minutes to complete each test. Both the pre- and post-test were worth 0.6% of the total course grade, equivalent to one of the weekly problem solving sessions. This paper discusses the results of Problem A, shown in the sidebar above.

You are hunting for an apartment with your friends. You have found two apartments with the same rent that both require you to pay your own utilities (i.e. electricity bill, gas bill, heating, TV, internet, phone). You want to estimate: which apartment will be cheaper?

- *What information would you need to know in order to solve this problem?*
- *Describe briefly how you would figure out each piece of information that you specified above.*
- *List the physics principles or concepts that you would need to use in order to determine which choice will be more efficient.*
- *Once you had this information, what would you do with it? Describe briefly in point form how you would use this information to make the comparison.*

Transfer Problem A, administered as a pre-test in week 7 (N=199) and a post-test in week 12 (N=188).

These transfer problems do not ask students to solve a particular problem, but rather probe for factors they believe would be important to consider. Inspired by Bransford and Schwartz's approach to transfer[7], we are more interested to find out how students are prepared to investigate novel problems, rather than their ability to solve them correctly at first glance.

In coding the data, we found that students tended to make assumptions and references to physical concepts in ways that cohered around particular models they had encountered in class. Four main models used to answer the question emerged from the data: Conduction, Radiation, Thermal Energy Balance, and Direct Estimate. These are summarized in Table 1 below.

A coding rubric was developed to assign a score to each model for each student response. The rubric detailed the characteristics of students' solutions where 0 represented an erroneous solution, 1 was partially correct, 2 was mostly correct and 3 is excellent. Models that were not referenced were coded as N. Two researchers independently coded 67 papers with 82% inter-rater reliability, and 75% of disagreeing scores were resolved with discussion. After verifying the reliability of the rubric one researcher coded the remainder of the data set. For analysis, these codes were collapsed into three categories: No reference (N), Weak models (rated 0 or 1), and Strong models (rated 2 or 3).

Not all responses were coded. Five problem-solving sections were chosen randomly and coded for each of the pre and post groups, giving N = 199 and N=188 respectively.

TABLE 1. Scoring categories for transfer Problem A. Students receive a score in each category of No Reference, Strong, or Weak. The Scoring Criteria summarize required elements for a Strong score.

Model	Key Concepts	Scoring Criteria
Conduction	Heat loss through walls and windows via conduction	Explicit mention of thermal conduction with majority of relevant variables (area, thickness, conductivity, temperature)
Radiation	Heat loss and gain through windows via radiation	Explicit mention of both heat loss via radiation through windows and heat gain via solar exposure or other radiative source
Thermal Energy Balance	Conservation of energy; consideration of thermal losses and gains to determine heating needed	Mention of avenues of heat loss and heat gain, where heat loss is replaced by heat gain
Direct Estimate	Calculation of energy consumption via appliance or heater power rating and estimate of time of usage	Mention of multiple appliances with different power ratings and estimates of usage times

RESULTS AND DISCUSSION

Results from the pre- and post-test are listed in Table 2 below. Examination of the data shows a few important results. The majority of students made significant mention of Conduction in their answers, but not of Radiation. While these topics were afforded approximately equal class time, conduction was discussed in depth in the context of home heating while radiation was largely presented in connection with the earth's energy balance and climate change.

Three of the models exhibited a significant difference in scores between the pre and post groups: Conduction and Thermal Energy Balance models both had a decrease in the number of strong models and an

TABLE 2. Summary of all scores for pre- and post-tests. Each test was scored in each of the four models.

Model	Score	# of students (% of group)			
		Pre (N=199)		Post (N=188)	
Conduction*	N	11	(6%)	22	(11%)
	Weak	138	(69%)	135	(68%)
	Strong	50	(25%)	31	(16%)
Radiation	N	113	(57%)	120	(60%)
	Weak	78	(39%)	64	(32%)
	Strong	8	(4%)	4	(2%)
Thermal Energy Balance*	N	15	(8%)	34	(17%)
	Weak	100	(50%)	104	(52%)
	Strong	84	(42%)	50	(25%)
Direct Estimate*	N	67	(34%)	37	(19%)
	Weak	118	(59%)	116	(58%)
	Strong	14	(7%)	35	(18%)

* χ^2 analysis shows pre/post differences to $p < 0.05$

increase in the number of N scores, and the Direct Estimate model shows the opposite shift.

We hypothesized that working on the final project might have enabled students to integrate more than one model in their solutions, but the data does not support this. In fact, the average number of Strong models per student declined from 0.78 to 0.64, but a 2-tailed t-test shows that this is not a significant change ($p < 0.32$).

The decline in Conduction and Thermal Energy Balance scores combined with the increase in Direct Estimate scores led us to wonder whether students in the post group were more likely to choose Direct Estimate to the exclusion of other models despite the complementary nature of the models. Table 3 addresses the question "For a student with a Strong model in one category, how many other models are also rated as Strong?"

TABLE 3. Pre/post comparison of number of Strong models for students with at least one Strong model.

Primary Strong Model	# Of Other Strong Models	Pre	Post
Conduction	0	16	15
	1 or more	34	16
Radiation*	0	0	2
	1 or more	8	2
Thermal Energy Balance	0	47	26
	1 or more	37	24
Direct Estimate*	0	6	26
	1 or more	8	9

* χ^2 analysis shows pre/post differences to $p < 0.05$

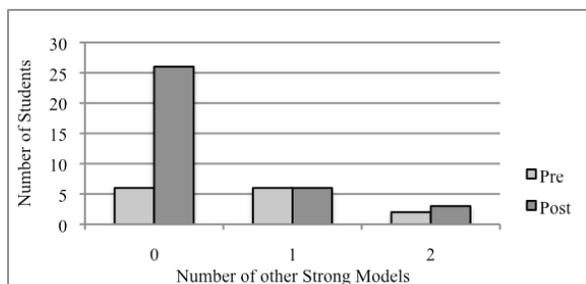


FIGURE 2. Number of other Strong models for students with Strong Direct Estimate models.

Table 3 shows that both Direct Estimate and Radiation show a significant difference in the number of other Strong models in the post-test group, but because the frequency of Strong Radiation models is so low the χ^2 test does not give reliable results. Therefore we focused our attention on the Direct Estimate model. From Table 3 we can see that while the total number of Strong Direct Estimate models increases, students in the post-test are far more likely to focus exclusively on Direct Estimate. Figure 2 above also illustrates this.

These results suggest that after completing the final project students are more likely to interpret Problem A in terms of Direct Estimates of power consumption alone. A review of the final projects completed by the students supports this notion. Very few of the projects demonstrated in-depth analysis of physical systems, with most relying on simple linear models backed up by estimates. In addition, the example final project provided for students is a comparison between incandescent and compact florescent light bulbs and uses a simple direct estimate (rate)*(time) model to calculate the energy usage of each type of bulb.

To examine how students are thinking about these models we also looked at the results of an attitudes survey that was administered after the post-test. One of the survey questions was “What did you learn on the final project?” Students gave a wide variety of answers to this question, some of which were coded as direct references to skill in applying particular physics models. Only 1% of responses cited knowledge relating to application of heat transfer models, whereas 10% cited knowledge relating to application of direct (rate)*(time) models.

Results of this study are attributed to the final project, and not other aspects of the course, because students’ are not expected to revisit concepts of heat between pre- and post-testing and there are no other opportunities for students to apply physics concepts to everyday problems. It is possible that retention is responsible for the decrease in references to heat transfer models in the post-test since the pre-test occurred soon after a midterm on heat concepts and those writing the post-test had yet to begin studying

for the final. Future work will investigate how this influenced their responses.

CONCLUSIONS AND FUTURE WORK

This evidence suggests that after working on the final project students are more likely to favor a simple direct estimate interpretation of Problem A. Thus, the final project has not significantly improved students’ tendency to apply broad physical principles such as conservation of energy to everyday problems. However, it does suggest that the final project may have improved students’ confidence in estimating and conducting (rate)*(time) calculations, which is certainly useful in everyday technical problem solving.

While these results are disappointing, they have implications for instruction that will support development of students’ real-world transfer abilities. We recommend explicit instruction on appropriate use of this type of simple model and on criteria for determining when additional sophistication is warranted. We also recommend that the final project rubrics and the initial in-class discussion of the final project encourage students to apply broad physics principles rather than simple (rate)*(time) estimates.

Future work includes an analysis of the responses to the parallel transfer problem (Problem B). We are interested in whether similar trends exist, thus providing additional evidence that the current final project fails to significantly improve students’ ability to apply physics concepts in real-world contexts.

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