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The Dependence of Instructional Outcomes on Individual Differences: An Example from DC Circuits

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Abstract. In a study of student understanding of the power dissipated through simple networks of resistors, two consistent, contradictory response patterns were identified: a greater equivalent resistance always dissipates more power, and a lesser equivalent resistance always dissipates more power. After completing one of two sequences of practice-questions, the performance of students who had initially thought that less resistance meant more power improved, while the performance of the opposing group did not — despite one of the practice sequences specifically addressing the idea that more resistance means more power. Because one prior conception appears to be susceptible to practice while the other does not, specific attention must be given to interactions between differing ideas and the physical concept being taught. If an instructor only examines the performance of the entire class, an overall increase in performance might mask a misalignment between instruction and the understanding of a significant, pre-defined number of students.

Keywords: DC Circuits, Preconceptions, Student Understanding, Individualized Instruction
PACS: 01.40.Fk,01.40.Ha

INTRODUCTION & MOTIVATION

It is commonly thought that students with differing learning "styles" will respond differently to different modes of instruction. The roots of the identification of learning styles lies in the work of Guilford [1], Bruner et al. [2], Pask [3], and others who studied the individual traits that affect learning outcomes in various situations. Much of the current research and curriculum development in the field of differentiated learning and instruction stems from a framework established by Chronbach and Snow [4], who demonstrated that there do exist correlations and interactions between student aptitudes and learning outcomes, which they described as Aptitude Treatment Interactions (ATI). In their studies, the term aptitude was used to refer to any "pre-treatment characteristic," which could refer to school achievement, socio-economic status, gender, etc.

In the term's most common usage, *learning styles* are exclusively limited to the traits of visual, auditory, reading and writing, or kinesthetic as described by Fleming and Mills [5]. Given the common usage of these and similar classification schemes, surprisingly, Pashler et al. [6] found in a review of literature that little concrete evidence has been published to support the claim that individuals learn best given their preferred learning style. In physics, for example, Kohl and Finkelstein did observe that when allowed to choose, students who chose a visual (or pictorial) format for a question outperformed students who were randomly assigned to a format in some situations. In other situations, students in randomly assigned formats outperformed those who chose visual formats. Achievement on tasks, therefore, could not be linked to preferred format [7].

Individual differences need not be constrained only to preference and ability, but also might include a wealth of prior experiences and learning — all of which can shape the ideas and concepts that students possess when they enter a formal physics-classroom. Using an operational definition of *preconception* to refer to some underlying mechanism that causes students to answer in some reliable and robust manner on a pre-instruction assessment, we propose that preconceptions can be considered to be aptitudes with which instruction might interact. Given different preconceptions about a single physical topic, therefore, it is possible to examine ATI's in physics education. Of primary concern for instruction is the extreme case of an aptitude treatment interaction whereby a particular instructional intervention increases performance by students with one level of an aptitude but reduces performance by students with a different level of the aptitude, as illustrated in Figure 5a). Such a crossover effect was proposed by Chronbach and Snow [4] and has been observed by several researchers [e.g., 8] in non-physics tasks.

To study the implications of differing preconceptions for differentiated instruction, topics must be identified that have multiple preconceptions. In this paper, one such example is presented: the power dissipated across networks of resistors. Once question-matter appropriate for study has been identified, differential instruction can be created to target the individual student or sub-population needs. An initial version of such a targeted intervention for power dissipation will be described as well as its ef-

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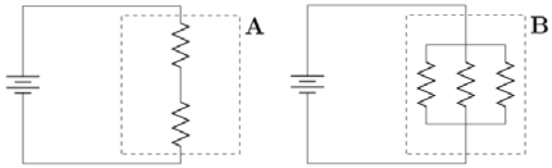

FIGURE 1. Students were asked: "Which arrangement of resistors dissipates more power?"

fects on student responses to related questions.

EXAMPLE FROM ELECTRICITY & MAGNETISM: POWER DISSIPATION

Students enrolled in a calculus-based, introductory electricity and magnetism course were asked to compare the power dissipation in three pairs of resistor configurations, two of which had common voltage sources, similar to Figure 1, and one with a common current source. Students completed these questionnaires as out-of-class homework assignments on LON-CAPA [9] during instruction in DC circuits. Out of the 119 students who responded, only 10% of students consistently answered correctly by evaluating $P = IV$ with the correct constraints. Meanwhile, 20% of the students consistently responded that a lesser equivalent resistance dissipates more power, and similarly 20% of the students responded that a greater equivalent resistance dissipates with more power. The remaining 50% answered inconsistently according to those three models.

The incorrect response patterns to the power-dissipation questions include correct responses for certain situations. If two resistor configurations share a common current source, the greater equivalent resistance dissipates more power. If, however, the resistor configurations share a common voltage source, the lesser equivalent resistance dissipates more power. Instruction, therefore, need not completely alter students' response patterns, but complete their conceptions so that students are able correctly identify when to apply their preconceptions and when it is necessary to apply different ideas.

In order to examine the effects of differential instruction, students were randomly assigned to complete one of two sequences of practice questions. This method of instruction was used in order to efficiently present *control-of-variable* arguments [10]. All questions were administered to students using LON-CAPA as out-of-class homework assignments [9]. After answering each question, students were shown the correct answer. No additional explanation was provided. In the Generic condition, students answered eight questions where resistors shared a common current source (as in Figure 2a) and eight questions where resistors shared a common voltage source (as in Figure 2b). Series and parallel configurations were evenly distributed throughout. The second practice condition, the Voltage condition, consisted of 10 common voltage sources and only 6 common current sources, thus providing students with more practice in situations for which a lesser equivalent resistance dissipates more power.

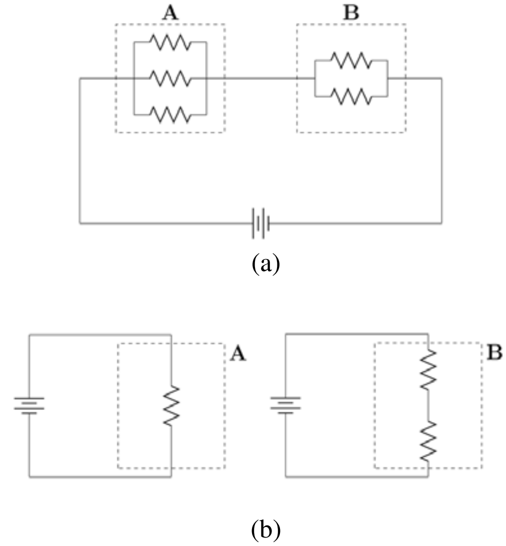

FIGURE 2. (a) Example showing common current source; (b) Example showing common voltage source.

Following the practice-sequences, students were questioned with 14 additional power-dissipation questions, seven of which shared common voltage sources and the others common current sources. In this preliminary study, data were not collected for a no-practice, control condition. However, since the only data that were examined originated from students who responded consistently on 3 out of 3 diagnostic questions with either "More Resistance/More Power" or "More Resistance/Less Power" responses, and since the 14-question testing sequence included 7 questions each where one of the responses was correct, it can be inferred that a null-effect of training would correspond to a post-test score of 7. This would be the score that they received if they continued with the same degree of consistent responses as displayed in the diagnostic questions.

Scores given students' preconceptions and practice conditions are shown in Figure 3. For students with the preconception that more resistance corresponds to less power dissipation, Generic practice (median score of 10; gain of 3) slightly outperforms Voltage practice (median score of 7.5; gain of 0.5). Since the Generic

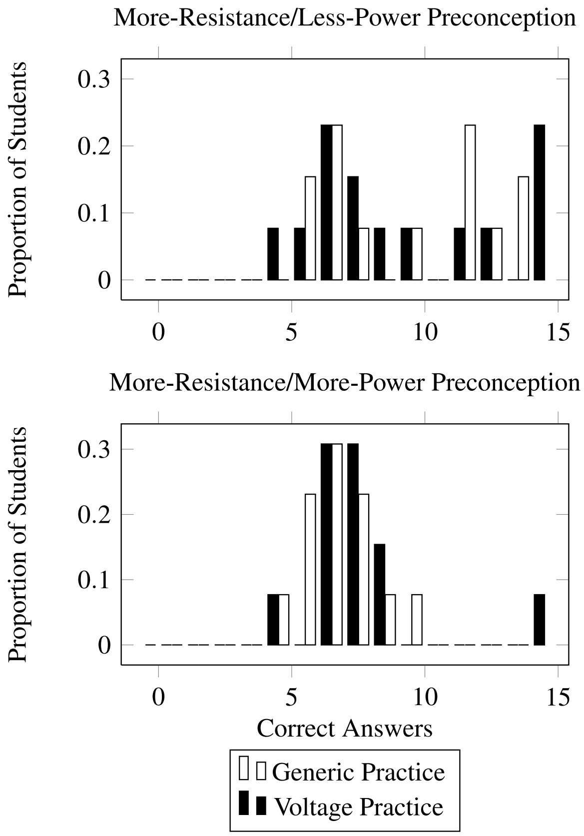

FIGURE 3. Results of instruction as a function of preconception and practice sequence. Of students with the More-Resistance/Less-Power preconceptions, 13 completed Generic Practice and 14 Voltage Practice. Of the students with More-Resistance/More-Power preconceptions, 13 completed Generic Practice and 12 Voltage Practice.

condition has a lesser proportion of common-voltage questions, it is possible that students are helped by the absence of additional less-resistance/more-power situations. This difference, however, is not statistically reliable (Mann-Whitney rank sum test: U=90, p=0.52) — most likely due to limited statistical power from the small sample sizes. There was no hint of difference for students with the more-resistance/more-power preconception. Both conditions resulted in median scores of 7 (gain of 0) and there was not a reliable difference in the distributions (Mann-Whitney rank sum test: U=109, p=0.39).

Since practice sequences did not affect student responses differently for given preconceptions, student results were pooled so that the main effect of preconception on student answers could be examined, as shown in Figure 4. Students with the more-resistance/less-power preconception (median score of 8) outperformed students with the more-resistance/more-power preconception (median score of 7). This difference was significant

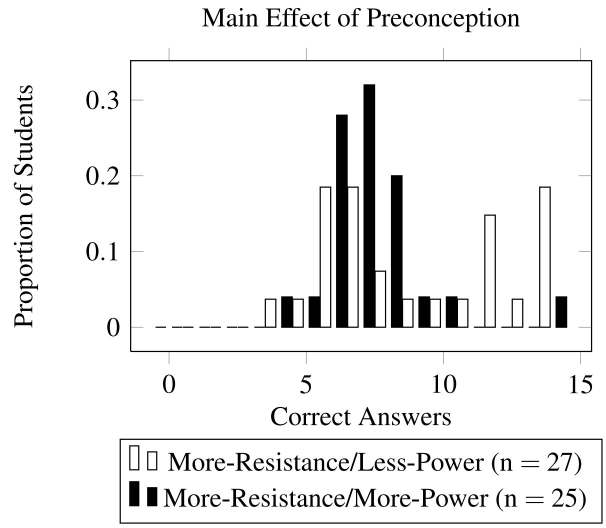

FIGURE 4. Results of instruction as a function of preconception only.

according to a Mann-Whitney rank sum test (U=446, p=0.04).

Discussion

A differentiated effect of instruction has been observed in the case of power dissipation. Unfortunately, any statistical analysis is greatly hampered by small numbers that result from examining subsets of subsets of students. For this preliminary study, therefore, we will comment only on the qualitative trends displayed by the data. Although there are hints that the Generic and Voltage conditions have different effects on the two preconceptions (Generic increased the score of more-resistance/less-power students more than Voltage, while neither condition favored the opposing preconception), there is not strong statistical evidence of an aptitude treatment interaction in this preliminary experiment. Drawing analogies from the terminology of analyses of variance (ANOVAs), an interaction plot can be drawn for the power-dissipation experiment as shown in Figure 5c. A significant crossover between preconception and instruction was not observed (as might be illustrated by Figure 5a). The experiment did, however, identify a main effect of preconception as illustrated in Figure 5b.

In this initial experimentation, the primary evidence suggests that different preconceptions are more susceptible to instruction than others. Students who begin the practice sequence by thinking that a lesser equivalent resistance dissipates more power respond more readily to either practice sequence than the students who respond that a greater equivalent resistance dissipates more

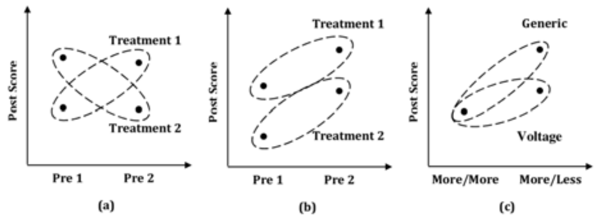

FIGURE 5. (a) Depiction of an ATI that displays a crossover effect Chronbach and Snow [4]. In this particular situation, each instructional intervention improves performance for one preconception and reduces another (or at least increases performance to a much lesser degree). (b) Depiction of main-effect of preconception where both instructional interventions help students with one preconception significantly more than students with an alternative preconception. (c) Qualitative depiction of actual power-dissipation data collected in this study. Note that the performance of students with both preconceptions is identical in the Voltage practice condition. Given statistical testing, this plot is qualitatively more similar to plot **b** than **a**.

power. While this does not directly highlight an *aptitude treatment interaction*, it does suggest that students with differing preconceptions do require differing instruction to be equally successful. This different instruction might be a similar practice sequence (with different questions) or an entirely different method of instruction. Perhaps students with the more-resistance/more-power preconception require explicit instruction in Ohm's Law and equivalent resistance, for example.

SUMMARY AND CONCLUSIONS

While we did not observe a classic crossover effect of instruction interacting with preconception, we did find evidence suggesting that students with different incorrect preconceptions about power dissipation respond differently to instruction. For most instructors, it is not surprising to physics educators that students begin physics coursework with conflicting ideas about physical concepts, nor should it be surprising that instruction can affect student responses. Of prime importance in this study is the presence of qualitatively different effects of instruction, both significant and insignificant, for cross between preconceptions and practice sequences. This interaction suggests that attention to individual student responses is necessary to potentially determine whether or not individualized instruction is necessary.

It is possible that in a large-enrollment physics class, a cross-over effect might be completely masked by an overall improvement if instruction is aligned with a sufficiently large portion of students' preconceptions. While this might be good for most, it is still possible that such instruction might actually push 15%-25% of the students farther from correctly answering a series of conceptual questions. Examining individual differences, therefore, is likely to produce additional, productive results and is worth additional study.

In future studies, attempts will be made to study both the effects of instruction on students possessing the previously identified preconceptions and the students who gave alternative, seemingly inconsistent responses. In order to strengthen the case for differentiated instruction driven by students' preconceptions, additional practice sequences will be administered in order validate the prior results and to explore further the effects of practice questions as a method of instruction. Furthermore, the effect of questioning will be accounted for by including a control condition in which student complete questionnaires without receiving the feedback-driven practice.

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