The case for individualized-instruction: Preconception-Instruction-Interaction

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Introduction

There has been much debate about the need for and the effectiveness of planning instruction around differing learning styles (e.g., visual, auditory, kinesthetic). For example, when studied in controlled environments, it has been shown repeatedly that instruction aligned with learning styles does appreciably correlate with increased understanding \(^1\). Alternatively, independent to the localized success of coursework, Felder argues that use of multiple learning styles helps to prepare students to work in situations that require different modes of learning and thinking \(^2\). The roots of learning-style research lie in the framework developed by Chronbach of Aptitude-Treatment-Interactions \(^3\), in which a student’s learning outcome is dependent not only on the instruction that has been administered, but also on the student’s aptitudes. An aptitude is classified as any “pre-treatment characteristic.” Learning-styles might be described as aptitudes – because a student’s preferred mode of instruction is likely determined prior to physics coursework – but if learning outcomes are independent of learning styles, they do not exhibit Aptitude-Treatment-Interactions.

Chronbach’s framework of Aptitude-Treatment-Interaction is not exclusively limited to learning styles, but rather, it extends to any pre-existing characteristic of a student prior to engaging with instruction. Many of the science, technology, engineering and mathematics disciplines have the unique situation in which students enter the classroom with a wealth informed ideas and intuitions that they have accumulated over a lifetime of interacting with the physical world. This is especially true introductory physics. Because these ideas existed prior to engaging with formal instruction (at least formal instruction at the university level), these pre-existing ideas, or preconceptions, fit the definition of aptitude.

If, therefore, we consider the possibility of learning outcomes differing for students with different preconceptions, Aptitude-Treatment-Interactions can be extended to Preconception-Instruction-Interactions. When attempting to recognize such an interaction, it is convenient to apply interaction-style plots and labels from statistical analyses (e.g., an interaction plot as might be produced as part of an analysis of variance). Such plots are shown in Figure 1, and it can be seen that several possible classes of Preconception-Instruction-Interactions are possible. First, there is the case whereby students might have differing preconceptions, but those preconceptions do not respond differently to different instructions. This is the case of a main effect of Instruction (Figure 1A). This occurrence is similar to learning-styles, for which students have differing aptitudes, but they do not affect the outcomes of instruction. Alternatively, students might be categorized with different preconceptions but for each preconception, students do not respond differently to instruction. This can be considered a main effect of preconception (Figure 1B) \(^4\). There is the possibility that students with one preconception consistently out-perform students with an alternative preconception – regardless of the instruction received. Such a case can be identified as having main effects of instruction and preconception (Figure 1C). Finally, it is possible that one mode of instruction benefits students with one preconception more than students with an alternative preconception. Meanwhile, students with the alternative preconception are helped more by a second mode of instruction. Such a situation is illustrated in Figure 1D and will be referred to as a crossover interaction.
A. Main Effect of Instruction

B. Main Effect of Preconception

C. Main Effects of Instruction & Preconception

D. Crossover Interaction of Instruction & Preconception

Figure 1: Plots showing the possible effects of instruction on differing preconceptions. In all plots, the horizontal axis is categorical and shows different preconceptions. This axis is not necessarily limited to two preconceptions. The vertical axis shows student performance on a summative assessment following instruction. Filled circles (●) indicate students who completed one instruction, while empty circles (○) indicate a different instruction. (A) shows a main-effect of instruction and no effect of preconception. (B) shows no main-effect of instruction and a main effect of preconception. (C) shows both a main-effect of instruction and a main effect of preconception. (D) shows neither a main-effect of instruction nor a main effect of preconception, but it does show a crossover interaction between instruction and preconception.

While only the situation illustrated in Figure 1D would be considered a statistical interaction term, anytime that both instruction and an individual’s preconceptions affect the learning outcomes, it should be considered a preconception-instruction-interaction (Figures 1B, 1C, 1D). The case described by 1D does merit special attention because crossover interactions indicate the possibility where one mode of instruction might aid some students to the detriment of others.

In this article, we present two simple, but canonical examples - the first mirrors learning styles where students with differing preconceptions are all affected uniformly by the same instruction (Main Effect of
Instruction) and the second where students with differing preconceptions are affected differently by differing instructions (Crossover Interaction of Instruction and Preconception). Although the examples that we present are narrowly defined, we intend not to present a comprehensive picture of Preconception-Instruction-Interaction, but rather, a method for exploring the effects of preconceptions on instructional-outcomes and a motivation for attending to fine-grain features of problems. Finally, we will discuss briefly the implications of Preconception-Instruction-Interactions on individualized instruction.

Example 1: Projectile Motion - Main Effect of Instruction, No Preconception-Instruction-Interaction

In this first example, students completed question sequences as required by a "flexible" homework assignment whereby they were required to participate in a physics education research experiment at some point during the academic term. These students were enrolled in an introductory, calculus-based physics course at large, public university, and completed the experiment in a physics education research laboratory by answering questions on laboratory computers.

In particular, students were presented with questions in which they were asked to compare the time of flight of two projectiles. Specialized stimulus-delivery software was used to present these questions and record responses. See Figure 2 for a screen capture from the Projectile Questionnaire.

![Figure 2: Screen capture of projectile motion question.]

Three possible preconceptions were identified from student responses: only to the relative heights of the two trajectories determines the relative times of flight, only to the relative ranges of the two trajectories
determines the relative times of flight, or there is some (potentially ill-defined) compensation between competing relative heights and ranges. These patterns were particularly evident when viewing responses to questions similar to Figure 2 in which one trajectory had a longer range but shorter height than the opposing trajectory. Figure 3 summarizes the responses of students to the question shown in Figure 2.

Figure 3: Without any intervention, 86 student responses were split between the correct response that the projectile with a greater height had a longer time of flight (55%), the incorrect, preconception-response that the longer range has a longer time of flight (19%), and the incorrect, preconception-response that range and height compete with each other equally so that the two trajectories have equal times of flight (26%).

Because students answered along both the height and range dimensions, two experimental-instruction conditions were developed: one in which students worked through example questions where the ranges were held equal and the heights varied (Equal Range Practice), and a second in which the heights were held equal but the ranges varied (Equal Height Practice). Examples of each type of situation are shown in Figures 4A and 4B, respectively.

Figure 4: Projectile comparisons where (A) the trajectories have equal ranges but differing heights and (B) the trajectories have differing ranges and equal heights.
Both instruction conditions proceeded in a similar way. Students were first directly asked which projectile was in the air for a longer period of time. Once they submitted their answer, the screen advanced to reveal the correct answer. Figure 5 shows such a question- and answer-slide sequence. In the Projectile Experiment, this process repeated 32 times, with 16 question-answer sequences unique to each instructional condition. The remaining 16 question-answer sequences were common to both conditions.

![Figure 5: Screen captures showing a question/answer practice sequence for projectile motion. (A) Students were first asked to decide which trajectory represents a projectile with a longer time of flight. (B) After responding to the question, students were shown the correct answer.](image)

For the Projectile Example a between-student design was used. Some students were questioned exclusively without training (Control), while other students completed one of the two training conditions. The resulting answer distributions are shown in Figure 6 side-by-side with the no-practice, control condition. Because it was a between-student design, a plot like those shown in Figure 1 could not be produced.

Examining the results, students in the Equal Range Practice condition responded that the trajectory according to the preconception that the greater range has a greater time of flight at equal rates to students in the control condition (Cohen’s $d$ effect size $\frac{r}{s}$, $d = 0.02$). While students who participated in the Equal Height Practice condition answered that the greater ranged-trajectory has the longer time of flight less frequently than the control condition (Cohen’s $d = -0.36$). This suggests that the Equal Height Practice condition was more effective at reducing the number of students with a More-Range, More-Time preconception. Additionally, both instructional conditions had fewer students applying compensating arguments to claim equivalent times of flight, with the more-range-equal-height condition having a more negative effect on answers of "Equal" (Cohen’s $d = -0.37$, and $d = -0.68$, respectively).

Examining the overall effect in correct answers, there was a moderate effect from the equal range-more height condition (Cohen’s $d = 0.28$), and a large effect from the more range-equal height condition (Cohen’s $d = 0.85$).
Figure 6: Student responses to the projectile comparison question after completing a practice sequence. 44 students completed the equal-range practice sequence and 54 students completed the equal height practice sequence.

The combination of a large positive effect on correct answers and the significant negative effects on both incorrect answers/preconceptions suggests that regardless of student preconceptions, the Equal Height Practice condition was more effective at leading students to answer correctly than the Equal Range Practice condition, which only decreased the number of Compensate answers. Such a result, in which a single instructional method can be the most beneficial for all students - regardless of preconception - can be thought of as a Main Effect of Instruction.

Example 2: Power Dissipation – Crossover Interaction of Instruction and Preconception

In this example, students at one institution again completed question sequences as required by a "flexible" homework assignment (similar to all students from the Projectile Motion example) while students at a second institution completed the question sequences as a required, but non-graded, homework assignment. Students at both institutions were enrolled in introductory, calculus-based physics courses.

All students were presented with questions in which they were asked to compare the power dissipated by two simple, resistor networks. In some networks, resistors were combined in series, and in others, the resistors were combined in parallel. All questions were presented to students via LON-CAPA. (One of the institutions involved in the study hosts a LON-CAPA server. For more general information see the LON-CAPA project's homepage.) A screen capture from the Power-Dissipation Questionnaire is shown in Figure 7.
In this experiment, all students were asked to respond to three “diagnostic” questions. Two of these questions asked students to compare the power dissipated across resistor networks on separate circuits (e.g., Figure 8A) and one asked students to compare the power dissipated across separate resistor networks on a single circuit (e.g., Figure 8B). After calculating equivalent resistances, it can be seen that for separate circuits (that have equivalent potential drops across the resistor networks) the lesser resistance dissipates more power. Alternatively, for single circuits (that have equivalent currents through the resistor networks) the greater equivalent resistance dissipates more power.

This combination of diagnostic questions provided three distinct response patterns that were indicative of underlying preconceptions. Out of the 292 students who completed this exercise, 40% consistently answered that that resistor network with a greater equivalent resistance dissipated more power, 16% consistently answered that the lesser equivalent resistance dissipates more power, and 4% consistently answered correctly that power dissipation depends both on resistance and current (or potential drop). The remaining 40% did not answer consistently within any one of these three categories.

**Figure 7:** Screen capture of power-dissipation question.
Upon completing the diagnostic questions, students then completed either one of three randomly assigned experimental practice conditions or a control condition in which they did not complete any practice questions. As with the projectile motion example, practice sequences consisted of students being asked to answer which resistor network dissipates more power, and upon answering, the students were then shown the correct answer. An example sequence is shown in Figure 9.
The three experimental practice sequences consisted of various combinations of questions in which either the lesser equivalent resistance dissipated more power (separate and equal power supplies) or the greater equivalent resistance dissipated more power (single circuit thus an equivalent current running both resistor networks). Unlike the diagnostic questions, the practice questions only included comparisons between two networks in which all resistors were all in parallel, or two in which all resistors were in series. Students were not asked to compare a series to a parallel network. This was done to ensure that the practice questions only varied one parameter at a time – whether or not the greater or lesser equivalent resistance dissipated more power.

The three practice sequences each consisted of 16 question/answer pairs. In one condition, the “More-Resistance-More-Power” condition, 12 questions were single circuits with equivalent currents, while only four were separate circuits with equivalent potential differences. In the “Balanced” condition, 8 questions consisted of a single circuit and 8 questions consisted of separate circuits. Finally, in the “Less-Resistance-More-Power” condition, only 4 questions included single circuits while 12 questions were included separate circuits. In all conditions, the number of practice questions that included parallel networks was balanced with the number that included serial networks. The training conditions are summarized in Table 1.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Single Circuit</th>
<th>Separate Circuits</th>
</tr>
</thead>
<tbody>
<tr>
<td>More-Resistance-More-Power Condition</td>
<td>4 Practice Questions</td>
<td>12 Practice Questions</td>
</tr>
<tr>
<td>Balanced Condition</td>
<td>8 Practice Questions</td>
<td>8 Practice Questions</td>
</tr>
<tr>
<td>Less-Resistance-More-Power Condition</td>
<td>12 Practice Questions</td>
<td>4 Practice Questions</td>
</tr>
</tbody>
</table>

**Table 1:** Summary of practice conditions that were administered to students in the power-dissipation experiment.

Upon completing the practice sequences, students were once again tested with the diagnostic questions, the results of which are shown in Figure 10. Since the number of students with the “Less-Resistance-More-Power” preconception was small, the results of the practice sequences cannot be analyzed statistically (especially after the additional breakdown into experimental conditions). The results, therefore, will only be described as suggestive.
Figure 10: The effects of the experimental practice conditions as measured by the test questions. (A) shows the post-practice answer distributions on the separate circuits question, for which the lesser equivalent resistance dissipates more power. (B) shows the post-practice answer distribution on the single circuit question, for which the greater equivalent resistance dissipates more power.

Examining Figure 10, it appears that the Less-Resistance-More-Power practice helps students learn how to answer the separate-circuit question, while the More-Resistance-More-Power practice helps students learn how to answer the single-circuit question. Furthermore, there is a hint that the Less-Resistance-More-Power practices to the single-circuit condition slightly better than the converse. Since the power-dissipation experiment used a within student design, an addition, more detailed analysis is possible. First, questions for which the correct answers coincided with students’ preconceptions can be examined, and second, questions for which the correct answers directly opposed students’ preconception. Examining the
questions that were aligned with preconceptions, Table 2A shows the responses of students with the Less-Resistance-More-Power Preconception on the separate-circuit test question. Table 2B shows the responses of students with the More-Resistance-More-Power Preconception on the single-circuit question. In both situations, the same pattern is observed. The no-training, control-condition did not affect student responses. Similarly, the practice conditions that were most closely aligned with preconceptions did not affect responses (e.g., students with the More-Resistance-More-Power preconception continued to answer the single-circuit correctly after completing the More-Resistance-More-Power practice sequence). However, as the proportion of practice questions that was aligned with the preconceptions and the test question decreased, students were more likely to switch their answers to the incorrect, opposing response (e.g. students with the Less-Resistance-More-Power preconception were more likely to answer the single-circuit question incorrectly – that the greater resistance corresponded to greater power-dissipation – after completing the More-Resistance-More-Power practice sequence).

<table>
<thead>
<tr>
<th>Training condition</th>
<th>Remains Correct</th>
<th>Move to Incorrect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (n=9)</td>
<td>100 %</td>
<td>0%</td>
</tr>
<tr>
<td>Less-Resistance-More-Power (n=11)</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>Balanced (n=8)</td>
<td>62%</td>
<td>38%</td>
</tr>
<tr>
<td>More-Resistance-More-Power (n=12)</td>
<td>50%</td>
<td>50%</td>
</tr>
</tbody>
</table>

A. Students with the less-resistance-more-power preconception

<table>
<thead>
<tr>
<th>Training condition</th>
<th>Remains Correct</th>
<th>Move to Incorrect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (n=30)</td>
<td>97%</td>
<td>3%</td>
</tr>
<tr>
<td>Less-Resistance-More-Power (n=31)</td>
<td>58%</td>
<td>42%</td>
</tr>
<tr>
<td>Balanced (n=31)</td>
<td>68%</td>
<td>32%</td>
</tr>
<tr>
<td>More-Resistance-More-Power (n=26)</td>
<td>96%</td>
<td>4%</td>
</tr>
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</table>

B. Students with the more-resistance-more-power preconception

**Table 2:** Effect of training on questions that were initially aligned with students’ preconceptions. Table A presents responses to the separate-circuits question from students with the less-resistance-more-power preconception. Table B presents responses to the single-circuit question from students with the more-resistance-more-power preconception.

Second, examining the questions that opposed with students’ preconceptions, Table 3A shows the responses of students with the More-Resistance-More-Power Preconception on the separate-circuit test question. Table 3B shows the responses of students with the Less-Resistance-More-Power Preconception on the single-circuit question. In both situations, a similar pattern is again observed. The practice conditions that were most closely aligned with preconceptions did not affect responses (e.g., students with the More-Resistance-More-Power preconception continued to answer the separate-circuit incorrectly after completing the More-Resistance-More-Power practice sequence). However, as the proportion of practice questions that was aligned with the preconceptions decreased and the proportion of questions that aligned with the test question increased, students were more likely to switch their answers to the correct response (e.g. students with the Less-Resistance-More-Power preconception were more likely to answer the single-
circuit question correctly – that more resistance corresponded to greater power-dissipation – after completing the More-Resistance-More-Power practice sequence).

<table>
<thead>
<tr>
<th>Single-Circuit Question (More R, More P)</th>
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<tbody>
<tr>
<td>Move to Correct</td>
</tr>
<tr>
<td>Control (n=9)</td>
</tr>
<tr>
<td>Less-Resistance-More-Power (n=11)</td>
</tr>
<tr>
<td>Balanced (n=8)</td>
</tr>
<tr>
<td>More-Resistance-More-Power (n=12)</td>
</tr>
</tbody>
</table>

A. Students with the less-resistance-more-power preconception

<table>
<thead>
<tr>
<th>Separate-Circuits Question (Less R, More P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Move to Correct</td>
</tr>
<tr>
<td>Control (n=30)</td>
</tr>
<tr>
<td>Less-Resistance-More-Power (n=31)</td>
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<tr>
<td>Balanced (n=31)</td>
</tr>
<tr>
<td>More-Resistance-More-Power (n=26)</td>
</tr>
</tbody>
</table>

B. Students with the more-resistance-more-power preconception

Table 3: Effect of training on questions that were misaligned with students’ preconceptions. Table A presents responses to the single circuit question from students with the less-resistance-more-power preconception. Table B presents responses to the separate-circuits question from students with the more-resistance-more-power preconception.

One might interpret the results of Tables 2 and 3 to be – on the surface – somewhat straightforward: students are more likely to respond in the same way that they just were trained. While this certainly appears to be an important issue for this particular training and testing sequence, the point is that the responses to training depend on the each student’s preconception.

In other words, a natural conclusion might be that a balanced mixture of Less-Resistance- and More-Resistance-More-Power practice questions should provide reasonable instruction for students from both preconceptions. However, the Balanced practice condition reduced performance for certain preconception/test question combinations as much as it increased the performance for other combinations. The primary observation of these data tables is not that one practice condition is necessarily better than the other as was true for the Projectile Example – rather that the different practice conditions affect the student differently depending on the preconception as shown in Tables 2 and 3. That is, there is a clear crossover interaction between instruction and preconceptions. One practice sequence can help students with one preconception, while reducing the performance of students with the alternative preconception.

Summary and Discussion

We studied the extent to which different training affects students with different preconceptions and found two kinds of results in two different experiments. First, in the projectile motion experiment, we found that one training improved scores for students with two different kinds of incorrect preconceptions, while
another kind of training only helped one population but did not affect the other. In this case, it is clear which kind of training to use for all students: the one that helps all students.

However, in the second experiment with electric power, we found a cross-over effect, namely that one training helped one population of students with an incorrect preconception, but hindered another population with a different incorrect preconception. In this case it is clear that individualized training is needed and determining the preconceptions of the students is critical.

While these results are based on only a couple very specific and isolated cases, these results should be placed in context as part of an investigation into the importance of individualized learning. As parts of American higher education become less and less centralized around colleges and universities, education becomes more centered on the individual. Since all learners are different, instruction should be flexible to adapt from one individual to the next.

In many situations, learning styles or overall level of achievement might used to categorize individuals. Learning styles have been repeatedly shown to be ineffective at for improving individualized learning, and although overall achievement is frequently used (e.g., GRE scores might be used for a first cut through graduate school applications), neither quite fits the role of informing and improving instruction for the individual. Knowledge about the learner’s current understanding can be integrated into the education plan. Although sometimes not necessary (as shown in Example #1 with projectile motion) a student’s preconceptions might change the potential effects of instruction (as shown in Example #2 with power dissipation).

Beyond the scope of individual learners, preconception-instruction-interactions might influence traditional lecture settings as well. It is possible that in a large-enrollment physics class, such as those from which many of the students were drawn for these studies, multiple, competing preconceptions might be present for various topics. As was the case for power-dissipation, a large portion of the class might have one preconception that masks equally robust competing preconceptions. A single instruction therefore, might appear to be effective as measured by a class-wide assessment, but a closer inspection could reveal that the instruction helped only the students with the majority preconception and served to further confuse students with the competing preconception.

Both for the case of a traditional, lecture-style environment and the case of the individual, decentralized learner, further exploration of preconception-instruction-interactions is warranted. In future studies, additional common physics preconceptions will be explored for instruction-interactions, the previously collected data from students who answered inconsistently on the diagnostic questions will be carefully analyzed, and alternative methods of instruction will be studied. For example, what would happen if students were simply told the rule, rather than shown worked examples? Would such a training still lead to a preconception-instruction-interaction?

Bibliography


