Improving Student Learning: The Dual Roles of Conceptual Understanding and Reasoning Ability

Paula R.L. Heron
Department of Physics, University of Washington, Seattle WA 98195-1560 USA
pheron@uw.edu

Abstract: Research shows that dual-process theories of reasoning – the fast and slow processes that govern reasoning and decision-making in everyday life – can explain student responses to physics questions. Examples and instructional implications will be discussed.

1. Introduction

As the field of optics grows in scope and technological importance, the questions of what to teach and how to teach are receiving increasing attention. While research on learning and teaching can inform the debate, choosing *what to teach* is largely a question of expert judgment. Experts can and will disagree on the balance between foundational and advanced topics and the order in which to introduce concepts, but the desired educational outcomes for students at different levels largely drive the discussion. The question of *how to teach,* on the other hand, can and should be addressed by systematic research.

A growing body of research findings has convinced many instructors of the need to understand learner' initial ideas, and of the need to engage them actively in the learning process. Active-learning instructional materials designed for traditional classrooms, small-group settings, laboratories, and online environments have been developed for a range of topics, including many in optics. While these advances have had significant impact in physics classrooms, there is still a great deal we don't know about how students think and about the processes by which they become more expert-like.

Among the overarching questions that persist are "Why do students make errors that directly contradict what they have been taught? Errors that don't arise from the failure to remember the correct formula?" For the past several decades, researchers have focused on one compelling explanation: students arrive in the classroom with pre-formed ideas about how the world works. Even though they may blend these ideas with those presented in formal instruction, the prior conceptions often win out. According to these accounts, students' prior knowledge has been built through rational, if imperfect, processes of observation and analysis, and any new or different ideas presented in the classroom must likewise be built, not simply received. Figuring out what ideas students bring with them to the classroom, and how to take them into account, has proven to be a complex, multi-faceted program of research that has significantly influenced physics teaching. However, it is not always the case that students produce incorrect answers through logical inferences based on incorrect or inappropriate premises – often they don't know *why* they chose a particular answer, just that it *seems right*.

2. Dual-process theories of reasoning

"Dual-process" theories of reasoning, introduced to the layperson by Daniel Kahneman in *Thinking Fast and Slow,* provide some insight [1]. These theories have long been used to account for observed inconsistencies in human reasoning. According to these theories, when faced with the need to make a decision or reach a conclusion, Process 1 (referred to variously as "fast," "intuitive," or "heuristic") produces an automatic and effortless first impression [2,3]. If this impression is found to be satisfactory, it will be adopted. Otherwise, the effortful and deliberate Process 2 (variously referred to as "slow," "reflective" or "analytical") is engaged. Researchers believe that this sequence cannot be "turned off." That is, a first impression will always be formed. These quick judgments are often accepted, in part due to universal tendency to avoid the effort needed to override an appealing intuitive impression and engage in process 2. This tendency toward "cognitive miserliness" allows many decisions to be dispatched quickly to preserve cognitive resources for important and complex decisions.

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3. Relevance in the physics classroom

In the physics classroom, students encounter numerous tasks that require responses and decisions: from responding to clicker questions during lectures, to solving homework and exam problems, to collecting and processing data in the laboratory. Students' incorrect or inefficient responses might not be based on "slow" thinking; instead they might be based on "fast" thinking. That is students immediately and effortlessly form a first-impression of a physics problem [4-5]. This output is frequently accepted, even if it is inconsistent with knowledge that a given student has expressed correctly elsewhere.

These findings suggest a number of challenges for instructors. One challenge is to recognize when students are relying on misleading intuition and when they are struggling to understand complex models and theories. "Screening" questions can provide some insight: when students who answer screening questions correctly stumble on subsequent problems that require the same concepts, it raises the possibility that their answers are not the result of logical analysis, but rather reliance on appealing but misleading first impressions.

Another challenge for instructors is to help guide students to respect their intuition as a valuable resource, but not to rely on its output without scrutiny. A third challenge is to assist students in developing adequate fluency with at least some skills so that they can reserve cognitive resources for unfamiliar problems and challenging multi-step problems [6].

4. Conclusion

Dual-process theories can explain a puzzling classroom phenomenon: the ability of students to demonstrate competence on some tasks but not on other, closely related ones, even though the knowledge required may be fully within reach. Judgments that arrive quickly and easily, coupled with the unconscious drive to avoid effort, may lead students to answer incorrectly even though some effort would pay off. Experts experience the same impulses. Moreover, they prize their intuition and depend on formal analysis. Presumably their intuitions are less often misleading, and their abilities to detect conflicts and sustain the effort to resolve them have been honed through time and experience. Dual-process theories thus provide a model for both understanding the experiences of learners and a path for developing expertise.

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6. References

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