Resource Selection in Nearly-Novel Situations

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We developed an iterative survey to study the process of resource selection in a specific nearly-novel situation – the design of vacuum tube diodes. Preliminary data from upper-level undergraduate physics majors suggest that the ability to identify diode function in simple circuits predicts the ability to construct diodes.

INTRODUCTION

We seek to understand how advanced students synthesize physics ideas in unfamiliar situations. We seek such a situation, rich in physics but not mathematically complex.

Though many people have heard of vacuum tubes, possibly in conjunction with old music amplifiers, television sets, or diodes, very few undergraduates have studied vacuum tube diodes. Upper-level physics majors – unlike introductory students – have studied most of the relevant physics in understanding vacuum tubes' operation, but they have probably not applied their knowledge to vacuum tubes specifically.

A "nearly-novel" situation is one for which students have studied all the relevant physics principles but have not previously synthesized the ideas in a specific setting. For example, graduate qualifying exam questions may contain nearly-novel situations. Studying student reasoning of nearly-novel situations gives us insight into issues of transfer of knowledge, coherence of understanding, and student epistemologies and metacognitive skills as they make sense of an unfamiliar concept, such as vacuum tubes.

We use a resources model to describe student reasoning and introduce the idea of "cognitive space" to make sense of nearly-novel situations.

Resources [1] are small units of thought. An individual resource may contain a factual unit [2] or p-prim [3], or it may be a belief about knowledge, a metacognitive strategy, or similar [4]. If two content resources are linked strongly together (e.g. they are often used together), we say they are "near" each other. Many strongly linked and well-rehearsed resources are near each other in a cognitive space and form larger conceptions not subject to constant sense-making [5]. A nearly-novel situation forces students into an uncharted area outside of established conceptions but still near many resources. In a nearly-novel situation, students are not expected to learn new principles; rather, they are expected to identify and connect nearby resources from distinct physics topics into a coherent description. The resources model describes sense-making behavior in nearly-novel situations while allowing for the analysis of both stable, committed ideas (conceptions) and quick, changeable ideas (applied p-prims).

Metacognitive resources can mediate [6] and expand problem solving strategy and are in turn mediated by epistemological resources [4], which gate access to specific content resources about the subject matter at hand. These four resource types – metacognitive, problem solving, epistemological, and content – are therefore deeply tangled. A study of one must also study, in some part, the others. Thus, a nearly-novel situation should yield insight into the complex sense-making process.

PHYSICS

Understanding vacuum tube diodes involves combining concepts from both electrostatics and thermodynamics. When ideal diodes permit current through, they act as perfect conductors. When they don't, they act as open circuits.

The simplest vacuum tube diode, the Edison diode, is a light bulb with a collector plate. As the filament heats, electrons boil off and form a cloud around it. When set to a positive potential relative to the filament, the collector plate will collect the ejected electrons, registering a current. In the slightly more sophisticated DeForest triode, a mediating grid is placed between the filament and plate. Slight voltage changes on the grid effect large current changes on the plate.

SURVEY

To study nearly-novel situations in the context of vacuum tubes, we surveyed junior and senior physics majors at the University of Maine. Most of these students were taking or had taken Electromagnetic Theory, which covers all the necessary electrical phenomena. All students had taken a sophomore-level lab course in which diodes are introduced as one-way current valves that act as either an open circuit or a wire, depending on orientation. In junior lab, some of them had built a simple p-n semiconductor diode.

Because a nearly-novel situation hasn't been thought about specifically, reasoning about it may take a significant amount of time. We carried out interviews with four University students and one high school physics teacher. We found that reasoning about this topic takes a few minutes for a first-pass answer and about 30 to 60 minutes for a thorough answer. To gather data more efficiently, we used the interviews to develop a survey. We do not report on interview data here.

A standard survey will ask similar questions in slightly different manners to probe the extent of student beliefs. For common, everyday subjects, students may hold stable conceptions that are unlikely to change while taking a survey. A long, detailed instrument is sufficient to probe their thoughts because their thoughts are assumed immutable during the time they spend on the survey. We don't expect students to be consistent in a nearly-novel situation. A survey with only a few questions tends to present a less complete picture, but also shortens the time frame for their ideas to develop. A standard survey is a posed daguerreotype; we need a snapshot of evolving thought.

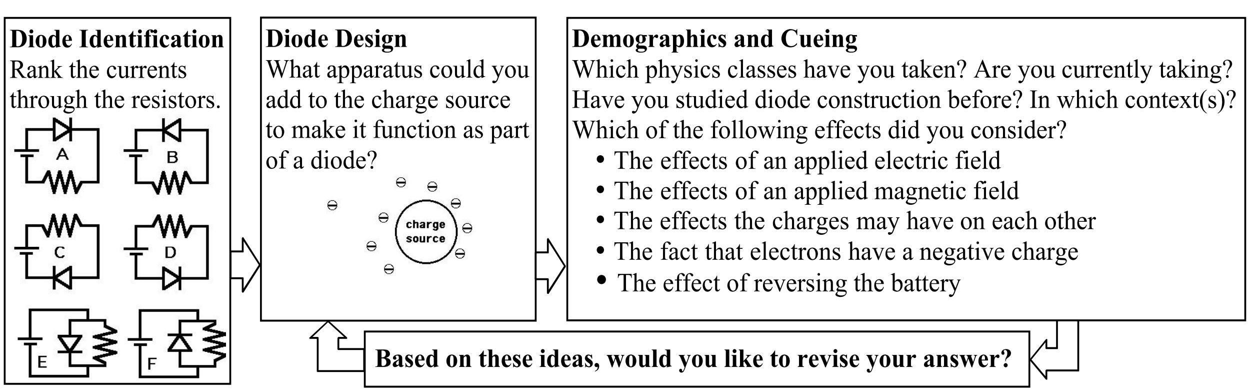
Our survey follows an iterative format to facilitate collecting multiple responses clearly separated in time. See Figure 1 for a flowchart of the survey's design. If students opt to redesign their diodes, they are not given an opportunity to return to their original response to change it.

In this paper, we describe survey data from eleven students. All answered the first questions about diode identification and construction, and seven answered the demographic and cueing questions that followed. Of those seven, four used their second opportunity to answer the diode design question. The paucity of people who completed all three segments may be attributed to three causes. Due to testing constraints, some students did not have enough time to complete the survey. Furthermore, if students felt their first answer was sufficient or if they could not think of how to change their original answer, they did not revise it. Students and survey administrators verified that all three explanations played a role.

Diode Circuit Identification

The survey starts with a diode circuit identification question. The currents through the six resistors (Figure 1) are ranked correctly as A=C=F>E>B=D=0 because E has vanishingly small, yet non-zero current. Alternately, the ranking can be A=C=F>B=D=E=0 because E's short circuit means that no current flows through the resistor. Two other rankings are possible for people who understand the role of diodes in circuits but misread the question. Students could rank the current through the diodes or the batteries.

Five of the students ranked their currents acceptably. Two of those five students were interviewees, surveyed after their interviews. With the first interviewee, diode current



identification had not been identified as a relevant task, so the interview did not involve diode identification. The other interviewee correctly identified the currents without prompting in his interview.

Of the six other students, one student did not completely rank the circuits. Her incomplete explanation claimed that, "current goes through resistor [D] and then can't go past diode," indicating some difficulties with the idea that current is the same everywhere in a simple series circuit. Her final ranking is classified as unacceptable, though borderline.

The remaining five students each had a different ranking. With varying degrees of clarity and success, they seem to believe that diodes are ohmic if turned on, but when biased backwards turn the current off. Their reasoning suggests that the Ohm's Law collection of resources – containing ideas about circuit behavior as well as Ohm's p-prim [3] – is too important to ignore in a question considering circuits. These students mis-apply an otherwise useful resource group when struggling with the nearly-novel situation of diode identification.

The diode-ranking question serves two purposes. For students, it defines a cognitive space for the following questions: this survey is about diodes. The questions prompt students to search for which resources are nearby. For researchers, the diode-ranking question shows who has problems with diode circuit identification. If a student doesn't know what a diode does, the student is unlikely to be able to design a diode.

Diode Design

After the preliminary diode identification question, students are asked to design a diode using a negative charge source, and to explain their reasoning. Student responses fall into three basic categories: true diodes, protodiodes, and unable to answer. True diodes are either semiconductor p-n junctions or vacuum tube-like devices. Protodiodes are a capacitor with the charge source in the middle, or an equal and opposite charge source next to the original source. They are not quite diodes, but with some tweaking could become them. Both models involve movement of charge through an unordered and usually empty space. The capacitor model could become a vacuum tube. The two-source model could become the junction model as the positive charge source morphs into a positively doped medium. Obviously, the line between true diodes and protodiodes is fuzzy. Student explanations of their reasoning were usually vague or incomplete, giving us little insight into the resources they may have used in designing their diodes. The third category contains students who are completely unable to draw a diode apparatus.

The first time students answered this question, two used semiconductors and three used vacuum tubes. Two of the vacuum tube drawers were interviewees and their drawings were identical to the ones produced during interviews. The five true diode drawers were the only students who answered the diode identification question correctly (see Table 1).

Three students drew protodiodes, and three were unable to answer the question. The students who designed protodiodes together with those incapable of designing a diode composed the entire unacceptable ranking group in the diode-ranking question.

Circuit Rankings vs. Diode Inventions	diode	protodiode	unable
acceptable	5	0	0
unacceptable	0	3	3

Table 1: Circuit Rankings vs. Diode Inventions. Note that only diode inventors can acceptably rank circuits, and vice versa.

Demographics and Cueing

After the first diode design question, the survey launches into some demographic questions about previous physics, engineering, and diode work (see Figure 1). The remaining questions explicitly start the process of reflection on the previous page's answers. A question asks, "A diode only allows current to flow in one direction. How confident are you that the diode you constructed will behave only as a diode?... Explain." This question, ostensibly about confidence, also explicitly tells students the function of a diode.

The next question asks students if they considered five specific physical effects in their diode designs (see Figure 1). They are to select all that apply. Of the listed effects, all but magnetism are relevant to vacuum tube diodes. However, interviewees brought up magnetism frequently. This question encourages students to consider these effects in a possible redesign of their diodes. Cognitively speaking, this question situates the diode design problem as an E&M problem and points to specific landmarks in the E&M landscape.

Four students chose to revise their diode diagrams. Two are especially interesting. For one student, diode design is not a nearly-novel situation. On his first pass, he drew a p-n junction. On his second pass, he drew the same junction and wrote that he needed more information about these materials before he could revise his answer. From his explanation, we know that diode design is not a nearly-novel situation for him: he built a p-n junction in a laboratory. He may be unclear about the details of semiconductor behavior or why p-n junctions perform like diodes, but this instrument cannot probe those ideas. The second person initially did not understand the question. She produced an unacceptable ranking and was unable to design a diode. After the cueing questions, she drew a positive lattice and wrote, "A diode is a junction of positive doped material up against negatively doped material." The survey does not mention junctions, and was not created with them in mind. The question that most likely jogged her mind was, "Have you studied the construction of diodes before? In what context(s)?" She wrote, "in lab – building one. in class – properties of pn junctions." She seems to view diode design as remembered stuff [6]: she cannot create a diode until she remembers what she has been taught in class. Her answer is not an explanation of reasoning, but rather a statement of fact.

DISCUSSION

We have developed a survey investigating student ability to reason in nearly-novel situations in the context of vacuum tube diode design. Initial data suggest that only students who can acceptably rank currents in simple diode circuits can produce a diode without further prompting. Also, we find that some students can be triggered to revise their answers, but give both seemingly memorized and not well-understood responses.

Because of the terseness and paucity of explanations, not much information about reasoning processes can be gleaned. Furthermore, since most survey respondents did not respond like interviewees, interviewee reasoning cannot be substituted for surveyed reasoning as extensively as is commonly done. We propose four solutions to these problems. More interviews in a clearer format should uncover additional reasoning, as well as more information about resource selection. More survey respondents will help clarify how the responses for each question relate to each other. A slightly rewritten survey to allow for semiconductor diodes will help tease out more accurate and complete answers as well. Finally, interviews with survey respondents might help uncover student reasoning while answering the survey.

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