Resource Activation Patterns In Expert Problem Solving

Darrick C. Jones*, Marina Malysheva†, AJ Richards*, Gorazd Planinšič‡ and
Eugenia Etkina†

**Department of Physics and Astronomy, Rutgers University, 136 Frelinghuysen Road, Piscataway, NJ 08845*

† Graduate School of Education, Rutgers University, 10 Seminary Place, New Brunswick, NJ 08901

‡ Faculty of Mathematics and Physics, University of Ljubljana, Jadranska 19, 1000 Ljubljana, Slovenia

Abstract: This paper describes the analysis of video recordings of physics experts solving novel problems involving solar cells, which involved such advanced physics topics as complex circuits and semiconductors. By performing a fine grained analysis using a resource based model of cognition, we determined what resources experts use while reasoning in the current context and how they used them. By analyzing critical events in the problem solving process, we searched for meaningful patterns of resource activation to help gain insight into expert problem solving processes.

Keywords: physics education research, resources, solar cells, experts

PACS: 01.40.-d, 01.40.Fk, 01.40.Ha

INTRODUCTION

To better understand and facilitate the learning process, we need to develop a model of sufficient detail which can provide causal explanations and allows for the individual and contextual nature of learning. [1] The resource-based model of cognition, [2] which posits that individuals contextually activate and combine fine grained bits of information, dubbed “resources,” to construct ideas that exist at a larger grain size, is a model which can support such a detailed investigation into the learning process.

Developing this model into a tool that can be useful for educators requires a focused effort into answering the following questions. 1. What resources do students have available to them? 2. What patterns of resource activation can be identified? This includes identifying the contextual dependency of resource activation as well as ways in which resources may be combined. 3. What resources and activation patterns are productive in which different contexts?

Previous work has begun to answer some of these questions in the context of novice studies. Resources have been classified and studies have gone on to identify how different resources are utilized by students. [2-6] More recent work classified resources and resource activation patterns utilized by novices as they learn about advanced physics topics. [7,8] Specifically, it was found that p-prims, conceptual, and epistemological resources are used simultaneously during critical moments of knowledge construction.

While we can answer the first two questions using studies that focus on the reasoning of novices, the third question cannot be answered deeply based exclusively on the analysis of novices. In order to more completely

answer this question, we need to study the reasoning of experts using a resource-based model of cognition. This is necessary because experts have amassed a great deal more content knowledge than novices and notice aspects of a problem that novices do not. [9] Confining studies to novice reasoning would miss the resources and patterns of resource activation which cause these differences.

In this study, we further develop the resource-based model of cognition by searching for and identifying productive resources and resource combination patterns present in expert reasoning. We do this through video analysis of problem solving sessions with physics experts who are asked to solve a complex, novel problem about solar cells. We focus particularly on determining whether critical moments in the problem solving process are characterized by the combination of p-prims, conceptual resources, and epistemological resources and whether any specific resources appear to be more important than others during critical events.

STUDY DESCRIPTION AND DATA COLLECTION

Assuring contextual relevance to the challenging classroom situations students commonly find themselves in is important when attempting to identify productive resources for knowledge construction from physics experts. This is because expertise is multidimensional, one dimension being related to procedural processes and another to novel experiences. [10] Common classification studies, such as the famous study by Chi et al. [11] and other studies that test expert performance on introductory level physics

TABLE 1. Transcript coded for resources

Example Segment of Coded Transcript Evidence of resources indicated by italic text	Resources in order of appearance Numbers match evidence in excerpt	Resource type
A: Yeah. When you cover up, when you cover up <i>one of the cells (1)</i> , that cell is now <i>just like a chunk of silicon that's not excited</i> . D: Right, it becomes like a...uh – A: Big resistor. D: Resistor, yeah.(2) A: Yeah. <i>So that's why (3) it's going to cut the current down a lot more. (4) If we, when we come in from the long side and just cover up parts of each cell, (5) then we're going to, um, none of the cells really become a resistor, (6) it's just like, um like, each of them is still contributing something. (7)</i> D: Ok. A: <i>So the effective resistance (8) is less than if we cover up one whole cell. (9) Does that make sense? (10)</i>	1. Discrete 2. Solar cell as resistor 3. Providing explanations which identify a mechanism 4. Ohm's P-prim 5. Continuous 6. Solar cell as resistor 7. Adding up 8. Solar cell as a resistor 9. Discrete 10. Encouraging sense making 11. Contrasting Cases (entire excerpt)	P-prim Conceptual Epistemological P-prim P-prim Conceptual P-prim Conceptual P-prim Epistemological Epistemological

problems, investigate the procedural dimension of expertise. If we want to understand what resources and resource activation patterns enable physics experts to gather more knowledge and reach understanding from this knowledge, then we need to look at studies which place experts in challenging, novel situations.

In this study, we maintain contextual relevance by using a novel problem about solar cells shown in Figure 1. We videotaped two pairs of experts as they solved the aforementioned problem. The experts were solicited through email and received no compensation. The first pair of experts was two physics graduate students. One was in his third year of study and the other in his sixth. This group worked to solve the problem over the course of 2.25 hours. The second pair of experts consisted of a physics faculty member and a postdoc. This group worked to solve the problem over the course of 1.25 hours. This difference in time was not a result of the second group solving the problem quicker, but a result of the first group having

more availability. Problem solving sessions were facilitated by members of the research team. The experts were given part 1 initially and asked to explain the phenomena described. Then they were given the handout for part 2 and asked to predict what would happen when the circuits in the handout were covered as shown. After, they were shown the actual measurements and asked to resolve discrepancies between their predictions and these measurements.

ANALYSIS

To begin analyzing the videotaped problem solving sessions, the videos were transcribed in full. The transcripts were then coded in two ways. First, the videos were coded for evidence of resource activation. We did this by reading through the transcript and marking passages which showed evidence of resource activation. Each passage was analyzed along with the

FIGURE 1. Handouts given to experts during videotaped problem solving sessions.

TABLE 2. Physics vs. non-physics critical events

Non-physics	Physics
Question: How does the construction of the solar cell make the two situations described in the problem unique?	Question: How do the individual p-n junctions function differently in the two situations and how does this explain the difference in the observed current vs. coverage graphs?
D: And so, so, that would mean that as you bring the paper in from this side, you're only partially covering them.	A: Yeah. When you cover up, when you cover up one of the cells, that cell is now just like a chunk of silicon that's not excited.
A: So that, yeah.	D: Right, it becomes like a...uh –
D: And then as you bring in the paper from this side...	A: Big resistor.
A: The long way.	D: Resistor, yeah.
D: You're, you're actually covering entire –	A: Yeah. So that's why it's going to cut the current down a lot more. If we, when we come in from the long side and just cover up parts of each cell, then we're going to, um, none of the cells really become a resistor, it's just like, um like, each of them is still contributing something.
A: Individual cells.	D: Ok.
D: Yeah. Yeah.	A: So the effective resistance is less than if we cover up one whole cell. Does that make sense?
A: Yeah...Yeah. So, so the difference between the two approaches is in one situation we're covering up like one cell at a time and on the other side we're covering up parts of all the cells.	

surrounding context to determine which specific resources were being activated and to classify each resource as either a p-prim, conceptual resource, or epistemological resource. Specific resource names were chosen based on resources identified in previous studies (such as [2-4]) or emergent trends in the data. We compared different passages which we identified as showing evidence of the same resource to maintain consistency. As a further check, a running list of all resources was kept and crosschecked. An example segment of coded transcript is shown in Table 1.

Second, the uncoded transcripts were separately coded for critical events using the guidelines set forth by Powell et al. [12] which identify critical events as instances during which conceptual breakthroughs or notably incorrect reasoning occurs, which lead to a sharp contrast between current and prior understanding. As a check on reliability, two coders were used to code 33% of the transcripts for critical events. The inter rater agreement was 82% (kappa = 0.46). After the discussion of the discrepancies we achieved a 100% agreement and a single coder proceeded to code the rest of the transcript alone.

While the below average agreement was originally concerning, during the discussion the second coder explicitly expressed difficulty understanding the physics being discussed by the interviewees. The first coder specialized in solar cell physics and had worked through the problem to completion, but the second coder did not specialize in solar cell physics and had only been told the solution to the problem. From this, we concluded that when investigating reasoning using complex problems, the nature of the problem makes it

difficult to perform proper reliability testing because both coders need highly specialized background knowledge and experience solving the problem.

After identifying critical events we reanalyzed them to determine the types of questions that subjects were trying to answer in each event. We classified these questions as physics or non-physics questions. Non-physics questions were pertinent to the problem, but focused on the engineering of the solar cell or strictly mathematical questions that could be answered without delving into the physics of the problem. A critical event of each type and the question answered during each event are given in Table 2.

Once we coded and classified critical events and resources we determined the percentage of critical events that showed evidence of all three types of resources (the pattern found by AJ Richards who analyzed problem solving of novices). [8] The results of this analysis are presented in Table 3. We found that 78% of all critical events showed evidence of all

TABLE 4. Most common epistemological resources

Knowledge can be gained through:
Reconciling observations with prior knowledge
Directly perceiving information
Representing information multiple ways
Being aware of one's own thinking (metacognition)
Being aware of other's thinking (social metacognition)
Being aware of explicit and implicit assumptions
Providing explanations which identify a mechanism
Building models which are consistent with observations/prior knowledge
Building models which predict and explain
Considering models as imperfect descriptors
Contrasting cases
Reasoning analogically
Encouraging sense making
Reasoning algebraically
Interpreting representations literally
Personifying inanimate objects
Requiring justifications

TABLE 3. Critical event types and resource activation

Event type	Number of events	Percent with all three types of resources
All	68	78%
Physics	50	86%
Non-physics	18	44%

three types of resources. When we distinguished between physics and non-physics critical events, the percentage of critical events showing evidence of all resource types rose to 86% for physics critical events and fell to 44% for non-physics critical events.

We also focused on epistemological resources that were activated during critical events due to the importance of epistemology for learning. [6,13,14] We found evidence of 46 epistemological resources in the full transcript. In critical events, 34 of the 46 were present. On average an epistemological resource was activated in 4.15 critical events. The 17 resources with above average activation levels during critical events made up 86% of the instances of epistemological resource activation during critical events. A list of these resources is given in Table 4.

DISCUSSION AND CONCLUSIONS

We set out to identify productive resources and resource activation patterns present in expert problem solving processes and we will now discuss what has been identified. We found an absence of at least one type of resource, i.e. a p-prim, conceptual, or epistemological resource, in a significant percentage of all critical events, a finding at odds with previous research investigating the reasoning processes of novices. [7] Previously, this pattern was observed in 88% of critical events, while we found this pattern in only 78% of all critical events. However, we found that by classifying critical events into physics critical events and non-physics critical events, we recreated this pattern strictly for physics critical events. Specifically, while the pattern only holds up for 78% of all critical events, the fact that the percentage of critical events with a p-prim, conceptual resource, and epistemological resource rose to 86% for physics critical events and dropped to 44% for non-physics critical events shows that the pattern holds up better for physics critical events than for all critical events.

The need to distinguish between physics and non-physics critical events in the present study, but not in the previous study is due to the nature of each study. Previous research was carried out during a concept construction lesson, while the current research used problem solving sessions as the data source. If we assume the instruction during the concept construction lesson guided students' attention to physics principles, rather than other mathematical or engineering details, we conclude that students in a concept construction lesson should have much fewer non-physics critical events than students engaged in problem solving.

The disparity in the types of resources present in the physics and non-physics critical events shows evidence that there are dissimilar reasoning patterns

occurring in each of the two types of critical events. Most often, 8/10 times, the resource that was lacking in a non-physics critical event was a conceptual resource. This is because the conceptual resources used to analyze the transcripts were largely physics oriented conceptual resources. If we investigated other types of conceptual resources, such as math and engineering conceptual resources, it is likely that we would see more similar behavior between the two types of critical events. Utilization of non-physics reasoning patterns in a physics problem is indicative of the multifaceted nature of problem solving which requires more than just knowledge of physics.

The overwhelming presence of a select group of epistemological resources in critical events shows that these resources have priority in the reasoning processes of experts. The priority is likely obtained through a selection process where less useful resources lose priority while more useful resources gain priority. This would mean that the resources found most often are most useful in the reasoning processes of physics experts. It is also important that while a select group of resources dominated the critical events, this group was still made up of a total of 17 resources. This means that there is a variety of epistemological resources that physics experts deem useful while problem solving.

REFERENCES

1. A. diSessa, in *The Cambridge Handbook of the Learning Science*, edited by K. Sawyer, (Cambridge University Press, New York, 2006), pp. 265-282.
2. D. Hammer, *Am J Phys*, **68** (7), S52-S59.
3. A. diSessa, *Cognition Instruct*, 10 (2-3), 105-225.
4. D. Hammer and A. Elby, in *Personal Epistemology The Psychology of Beliefs about Knowledge and Knowing*, edited by B.K. Hofer and P.R. Pintrich, (Lawrence Erlbaum, Mahwah, 2002), pp. 169-190.
5. D. Hammer, *J Learn Sci*, 5(2) 97-127 (1996).
6. L. Lising and A. Elby, *Am J Phys*, **73**, 372-382.
7. A.J. Richards and E. Etkina, in *AIP Conf. Proc.* 1513, Philadelphia, PA, 2012, pp. 330-333.
8. A.J. Richards, Ph.D. dissertation, Rutgers University, 2013.
9. J.D. Bransford, A.L. Brown, and R.R. Cocking, *How People Learn: Brain, Mind, Experience, and School*. (National Academy Press, Washington, DC, 2000), pp. 31-50.
10. D.L. Schwartz, J.D. Bransford, and D. Sears, in *Transfer of learning from a modern multidisciplinary perspective*, edited by J.P. Mestre (Information Age Publishing, Greenwich, CT, 2005), pp.1-51.
11. M.T. Chi, P.J. Feltovich, and R. Glaser, *Cognitive Sci*, **5** (2), 121-152.
12. A.B. Powell, J.M. Francisco, C.A. Maher, *J Math Behav*, **22** (4), 405-435.
13. D. Hammer, *Cognition Instruct*, **12** (2), 151-183.
14. D.B. May and E. Etkina, *Am J Phys*, 70, 1249-1258.