Introductory physics students' epistemological resources

Erin Scanlon[1,2]

[1]*Curriculum and Instruction, Texas State University, 601 University Dr., San Marcos, TX, 78666*
[2]*Physics, Texas Lutheran University, 1000 W. Court St., Seguin, TX, 78155*

A qualitative investigation was conducted of the epistemological resources employed by introductory physics students while solving physics problems in groups. The purpose of this study was to identify the resources employed by introductory physics students and the associated usage patterns of these resources. The epistemological resources were identified using emergent coding and by implementing an operationalized coding scheme from Jones (2015). 25 distinct epistemological resources were identified such as Peer Cognitive Awareness, Mathematical Reasoning, Invoking Authority, and If It's Given It Must Be Used. Students were categorized into groups based on their previous number of mathematics and physics courses completed. Future research will focus on teasing apart the source of the group differences as well as the effect of the different physics problems on student resource usage.

I. INTRODUCTION

In recent years the PER community has conducted research pertaining to physics students' epistemologies of physics due to the profound influence of these epistemologies on student learning [1]. Numerous studies conducted were framed using the Epistemological Beliefs framework in which beliefs are coarse grained, relatively stables conceptions held about the nature, source, and justification of knowledge [2]. The purpose of this study was to investigate introductory physics students' epistemologies at a finer-grain size in order to reach a longer term goal of comparing students' mathematics and physics epistemologies. Therefore, this study was shaped by the Epistemological Resources framework [3]. In this framework, students' epistemologies are composed of fine-grain pieces of cognitive structure that color how students view the world. The activation (or inhibition) patterns of epistemological resources are shaped by prior experiences. Unlike the Epistemological Beliefs framework, student epistemological resources are not considered as "novice" or "expert" but instead are conceived of as appropriate or inappropriate usage of these resources. Previous research has deduced a multitude of epistemological resources through qualitative investigation [4].

While the literature does not have an all-inclusive list of epistemological resources, one commonly employed epistemological resource by introductory physics students is Invoking Authority [5]. When this epistemological resource is employed, students trust information that comes from an authoritative source (e.g., teacher, textbook, Google, trusted peer). This epistemological resource can be seen in problem solving when students quote a rule, cite the textbook, or justify their responses by saying something to the effect of "because the teacher told me so".

This study is part of a larger study intended to investigate differences in epistemological resource activation between introductory physics students' mathematics and physics problem solving. The purpose of the study presented here was to investigate the breadth and range of epistemological resources used by introductory physics students. Specifically, the research questions that guided this inquiry were 1) Which epistemological resources do physics students use as deduced from their group discussion while solving physics problems? and 2) What is the nature of physics students' epistemological resources and their frequency of usage?

The following sections will include a discussion of the methodology employed in this study (Section II), presentation and discussion of the epistemological resources and their associated usage patterns findings of introductory physics students (Section III), and the conclusions and implications for future research (Section IV).

II. METHODOLOGY

The data for this study were collected in introductory, algebra-based physics courses offered at a small, private, Liberal Arts university in Central Texas. These specific courses were designed for life science students and have course content tailored for the chemistry, biology, kinesiology, and prehealth profession major students that typically enroll in these courses. These courses were taught with a combination of traditional lecture and more reformed pedagogical techniques including in class problem solving of context-rich problems.

In order to determine the epistemological resources employed, students were observed while solving physics problems in an authentic context in order to determine the resources used in a "natural" setting. Students were audio recorded while solving problems in the laboratory setting that is a required component of the course. At the end of each laboratory, students were tasked with conducting a group think-aloud over the last problem of the lab. The students were prompted to say everything that came to their mind, to thoroughly discuss the problem itself and their thinking about the problem, and to actively discuss with their group members. The problems solved ranged in type (e.g. conceptual, quanti-

2016 PERC Proceedings, edited by Jones, Ding, and Traxler; Peer-reviewed, doi:10.1119/perc.2016.pr.072

tative), topic (e.g. kinematics, dynamics, electric fields), and difficulty in order to determine the range of resources employed by introductory physics students. Transcripts of the audio recordings of these group think-aloud sessions were the main source of data for this study.

After the courses were completed, the students were grouped based on their self-reported number of previously completed mathematics and science classes. Of the 15 unique students enrolled in these courses, there were 6 in the lower mathematics, lower science group (0 to 2 mathematics courses and 0 to 5 science classes), 5 in the lower mathematics and higher science group (6 or more science classes), and 3 in the higher mathematics and higher science group (3 or more mathematics classes). Students were grouped by their previously completed courses because the literature indicates that epistemological resource usage should be based on prior experience [6]. For each group, one participant was chosen based on their participation in the discussion and technical quality of the audio recording (e.g., ability to hear the whole discussion). Audio recordings were then selected to be included in the data sample such that the chosen participant for each group worked with one other participant from each of the three groups for a total of nine problems included in the analysis. This means that each audio recording was selected so that in total each selected participant worked with a Low-Low participant, a Low-High participant, and a High-High participant. The grouping of students was done post-hoc and the pairing of students during the laboratory each week was independent of the grouping described above.

In order to characterize the nature of participants' physics epistemological resources, a systematic qualitative analysis was conducted. The transcripts of the participants' group think-aloud audio recordings were analyzed to identify, qualify, and classify students' physics epistemological resources. In order to determine the students' epistemological resources, content analysis was conducted on audio recording transcriptions in two phases [7]. During the first phase, emergent coding was used to determine the epistemological resources used by students without coloring the analysis with predetermined or literature-based coding schemes. In the second phase, an established coding scheme and methodology was used to include literature based epistemologies in the data analysis [8]. This coding scheme was highly operationalized and was developed by observing the resource usage of physics experts. The operationalization scheme was implemented and coded iteratively throughout the data sample (e.g. each resource was coded individually, one-by-one throughout the data sample).

III. FINDINGS AND DISCUSSION

A. Epistemological Resources

Through the emergent and established content analysis of the transcripts of introductory physics students' group think-aloud discussion of physics problems, 25 total epistemological resources were identified and are listed in Table I. Of the 26 epistemological resources identified, 9 were emergently identified and 16 were determined using the established coding scheme [8]. Table I shows the total numbers of instances that a particular epistemological resource was employed by each group (lower mathematics and lower science, lower mathematics and higher science, and higher mathematics and higher science groups), the total number of instances coded for each resource, and the number of problems in which each resource was identified out of the nine total problems. Resources identified using the established coding scheme are indicated with an asterisk (*). At the bottom of the table is the total number of of instances in which each epistemological resource was employed (broken down by group) along with the the number of unique participants from each group included in the sample. Future research will investigate the differences between groups of students and therefore the data are presented for each group separately.

Table I shows that a total of 837 instances of epistemological resources were identified in 9 problems. An average of approximately 90 epistemological resources per problem solving session that were, on average, 15 minutes. This implies that observations of students' problem solving leads to a plethora of epistemological resource usages and therefore can be similarly employed in future studies.

The Mathematical Reasoning epistemological resources were based off the Mathematical Reasoning code from an established coding scheme [8]. The original established code was identified when the person discussed or manipulated an equation, used a graph, and/or discussed the mathematical relationship or the form of the relationship between variables. The established code was broken down into three separate Mathematical Reasoning codes (e.g., Mathematical Reasoning 1-3) to further capture the different types of mathematical reasoning employed by the participants. Specifically the criteria for identifying these resources are Mathematical Reasoning 1 is discussing an equation, relationship between variables or the form of a relationship, Mathematical Reasoning 2 is manipulating an equation, and Mathematical Reasoning 3 is using a graph.

Of note is that multiple resources were employed a similar number of times between the three groups (e.g. Calculation, Equation, Mathematical Reasoning 1, Peer Cognitive Awareness, and Physical Intuition). The groups were formed under the assumption that due to their differences in previous mathematics and science training these students would employ different resources but some of the resources were similarly applied. Whether this common application is a sign of a common epistemology amongst introductory physics students or due to similar epistemologies among the students, to the details of the problems solved, etc. should be investigated in future research.

Also in Table I, different among groups is the usage of many of the particular resources. For example, only the lower mathematics and lower science group were observed to employ the emergently identified If It's Given It Must Be Used

TABLE I. Epistemological resources used by physics students.

Epistemological Resource	Low-Low	Low-High	High-High	Total	Problems Present
Calculation	17	13	18	48	8
Causal Reasoning *	0	2	2	4	4
Consistency *	1	1	5	7	4
Contrasting Cases *	15	5	10	30	7
Deductive Reasoning *	5	1	9	15	5
Equation	43	38	36	116	8
Experimentation *	0	3	0	3	1
If It's Given It Must Be Use	7	0	0	7	3
Inductive Reasoning *	1	3	0	4	3
Invoking Authority	34	19	22	75	9
Knowledge as Fabricated Stuff *	0	2	0	2	1
Knowledge from Direct Observation *	2	3	5	10	5
Limitations of Model *	5	2	1	8	3
Mathematical Reasoning 1	46	42	42	130	8
Mathematical Reasoning 2	30	28	19	77	8
Mathematical Reasoning 3	1	6	16	23	2
Meaning to Symbols	10	3	8	21	5
Mechanistic Reasoning *	0	1	4	5	2
Multiple Representations *	9	1	8	18	7
Peer Cognitive Awareness *	75	57	53	185	9
Personal Cognitive Awareness *	1	0	4	5	2
Physical Intuition	1	1	0	2	2
Plausibility *	3	0	0	3	2
Relative Value of Knowledge *	0	0	1	1	1
Sense Making *	0	0	1	1	1
Total	318	248	271	837	9
Number of Participants	4	3	3	10	

epistemological resource. Specifically, this resource was employed by two of the four participants in this group. This resource was identified if the participant expressed that when solving a problem they must use all the information given in their solution or their answer was incorrect. This may suggest a different level of sophistication of epistemological resource usage amongst the groups.

These and other group differences implies that there may be differences in epistemological resource usage by the participants previous experience in mathematics and science. Future research will be conducted to more finely tease apart the characteristics and sources of the differences between groups and between individual students with differing background academic variables (e.g. number of previously completed mathematics and science classes, incoming attitudes and beliefs, incoming physics-specific content knowledge, number of years in college).

A sample excerpt from the data set is displayed in Table II. In this excerpt, students A and B were discussing a circuit problem comparing the current through resistors in the circuit when a switch was open and when it was closed. In this short excerpt students A and B employed a total of 13 epistemological resources. The problem tasked the students with symbolically and numerically calculating the current through each resistor which may account for numerous instances of Mathematical Reasoning 1 and Equation being employed. Equation was an emergent code while Mathematical Reasoning 1 was based on the established coding scheme. The operationalizations of these two codes were nearly identical and the fact that these resources were commonly coded in this excerpt (e.g. each time there was an Equation code there was also a Mathematical Reasoning 1 code) implies a good alignment between the emergent and established coding. This supports the reliability of the coding process. In future research, these codes will be combined due to their large overlap.

This excerpt also shows an example of the established code Multiple Representations which is coded when the student invokes representation other than verbal communication. For example, the student may employ a graph, a diagram etc. In the original operationalization, equations were considered a representation type but due to the large number of instances of an equation being employed, a resource coded called Equation was made to better capture the types of representations used by students. In this instance, student B is using a diagrammatic representation of the circuit in order to enhance his understanding.

TABLE II. Sample coded transcript.

Transcript	Resource Coded
A: Okay, so-oh. So the current through R one is gonna be the same as the overall current. (1)	1. Consistency 2. Deductive Reasoning 3. Mathematical Reasoning 1 4. Equation
B: Mmmm....[groans]	5. Multiple Representations
A: Because it's just in series. (2) [pause] So. I total is equal to I one or I one is equal to I total. (3, 4)	6. Equation 7. Mathematical Reasoning 1 8. Equation
B: Oh the current-yeah. Okay so, I'm gonna redraw (5) this sucker.	9. Mathematical Reasoning 1 10. Invoking Authority 11. Equation
A: I total is equal to I one. (6, 7) Um...delta V B is equal to I total times Req closed. (8, 9, 10) So I total is equal to Req closed. Plus R three. (11, 12)	12. Mathematical Reasoning 1

B. Frequency of Usage

In order to address the second research question, a broad analysis of the epistemological resource usage patterns was conducted by determining the frequency of usage for each epistmeological resource. The total number of instances and percent of total instances coded for a particular resource along with the number of problems in which the resource was identified (out of nine total) were determined. These findings are listed in order of decreasing frequency of usage in Table III.

TABLE III. Epistemological resource usage patterns.

Epistemological Resource	**Total Instances**	**% of Total Instances**	**Problems Present**
Peer Cognitive Awareness *	185	22.10	9
Mathematical Reasoning 1	130	15.53	8
Equation	116	13.86	8
Mathematical Reasoning 2	77	9.20	8
Invoking Authority	75	8.96	9
Calculation	48	5.73	8
Contrasting Cases *	30	3.58	7
Mathematical Reasoning 3	23	2.75	2
Meaning to Symbols	21	2.51	5
Multiple Representations *	18	2.15	7
Deductive Reasoning *	15	1.79	5
Knowledge from Direction Observation *	10	1.19	5
Limitations of Model *	8	0.96	3
Consistency *	7	0.84	4
If It's Given It Must Be Used	7	0.84	3
Mechanistic Reasoning *	5	0.60	2
Personal Cognitive Awareness *	5	0.60	2
Causal Reasoning *	4	0.48	4
Inductive Reasoning *	4	0.48	3
Experimentation *	3	0.36	2
Plausibility *	3	0.36	2
Knowledge as Fabricated Stuff *	2	0.24	1
Physical Intuition *	2	0.24	2
Relative Value of Knowledge *	1	0.12	1
Sense Making *	1	0.12	1
Total	837		9

The most commonly employed epistemological resource was Peer Cognitive Awareness. This resource was coded if the student asks their partner a question or for clarification, or they reference something their partner had previously stated. Due to the fact that the data were collected during the laboratory portion of the courses where the participants were specifically prompted to discuss and work with their partner, it is expected that the number of instances for this resource should be high.

Another interesting pattern is that many of the established codes (derived from physics experts' problem solving) were employed a low number of times (e.g. Causal Reasoning, Inductive Reasoning, Experimentation, Plausibility, Relative Value of Knowledge, and Sense Making). This could be interpreted as a difference in the types of resources used between novices and physics experts but due to the purpose of the study being to determine the breadth and the scope of the resources used by introductory physics students, this hypothesis must be investigated in future studies.

IV. CONCLUSIONS AND IMPLICATIONS

This study investigated the epistemological resources and their associated usage patterns employed by introductory physics students. 25 unique epistemological resources were identified by observing students solving and discussing physics problems during the required laboratory component of the course. Different resources and resource usage patterns were identified between groups of students that differed based on their number of previously completed mathematics and science courses. The usage patterns differed amongst the resources; more of the established resources were coded less frequently possibly owing to their derivation from observations of physics experts.This study was intended to give a broad view of the epistemological resources employed by introductory physics students as well as the foundation for future studies. Based on this study, future research should focus in two main avenues. Firstly, a more in depth characterization of the group differences in epistemological resources and usage patterns should be conducted. Secondly, observations of student problem should be conducted in a different authentic setting (e.g. office hours) in order to determine if the same resources and usage patterns appear under different research circumstances.

[1] L. Lising and A. Elby, Am. J. Phys. **73**, 372 (2005).
[2] A. Madsen, S. B. McKagan, and E. C. Sayre, Phys. Rev. Phys. Educ. Res. **11**, 010115 (2015).
[3] D. Hammer and A. Elby, Sci. Educ. **85**, 554 (2001).
[4] D. Hammer, A. Elby, R. Scherr, and E. F. Redish, in *Transfer of Learning from a Modern Multidisciplinary Perspective*, edited by J. Mestre (Information Age Publishing, 2005).
[5] T. Bing and E. Redish, Phys. Rev. Phys. Educ. Res. **5**, 020108 (2009).
[6] D. Hammer, Am. J. Phys. **68**, S52 (2000).
[7] M. Miles, A. Huberman, J. Saldaňa, *Qualitative Data Aalysis: A Methods Sourcebook* (Thousand Oaks, California, 2014).
[8] D. C. Jones, Ph.D. thesis, Rutgers University, 2015