

# How students justify their knowledge in the Investigative Science Learning Environment

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This paper presents a preliminary investigation into how introductory physics students justify their knowledge in an investigative science learning environment (ISLE). ISLE attempts to help students learn physics using the same strategies that physicists use to construct their knowledge. A coding schema, from naïve to scientific knowing, is used to analyze students' justification of knowing, probed by open-ended and multiple-choice “convincing” questions. Results of the study support the assertion that students' epistemological beliefs are made as “context-sensitive resources.” The results further suggest that the way that students develop the resources in a particular context may affect their justification of knowledge. ISLE helps students not only understand the concepts, gain the knowledge of the experimental evidence supporting the concepts, but also may enrich their epistemological development.

## I. INTRODUCTION

Many studies [e.g., 1-6] have identified a relationship between students' epistemological beliefs and their motivation, academic performance, personal learning strategies, and learning environment. In the domain of introductory physics, a few researchers have done some pioneering work to study epistemologies. For instance, Hammer's research [7] sets up a framework of dimensions for beliefs about the structure of physics knowledge, the content of physics knowledge, and the process of learning physics. An instrument to measure some of these interrelated dimensions and others, the Maryland Physics Expectation survey (MPEX) [8], has been developed and used in a wide variety of introductory physics classes. The six aspects of belief surrounding physics in MPEX, however, do not include students' justification of knowledge. In addition, results of MPEX indicate that the change from naïve to expert beliefs in epistemology is hard even after students experience innovative instruction with active learning components.

This paper reports a preliminary study to investigate how introductory physics students justify their knowledge in an investigative science learning environment (ISLE) [9]. By exploring this question, it is hoped to expand the understanding of students' epistemologies, to

evaluate the effectiveness of ISLE, and to explore the implications for instruction. The study's design is explained in the next section. This is followed by a section presenting the instruments, a qualitative coding schema, and quantitative results. Finally, implications for instruction and future research are discussed.

## II. DESIGN OF THE STUDY

### Samples

ISLE students were chosen from an introductory calculus-based electricity and magnetism (EM) class at a medium-sized public teaching-oriented institute in Northern California. The subjects had one three-hour laboratory and three one-hour lectures each week (with the same instructor for both the lecture and laboratory). A sample of introductory EM students from a large research university in the Midwest was also chosen on a voluntary basis. These non-ISLE students experienced typical instruction.

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ISLE [9] attempts to help students learn physics using the same strategies that physicists use to construct their knowledge. These strategies include using experimental evidence for knowledge construction, model building, and experimental testing of models. In addition, other proven thinking and learning strategies, such as

multiple representations of a physical process [10], cooperative group learning [11], and weekly reports [12], were adapted. This ISLE course was centered around the laboratory: for each conceptual unit, students worked in an assigned mixed-abilities and mixed-majors group of 3-4, conducted observational experiments, constructed their own qualitative explanations to account for the observations, and then designed additional experiments to test these explanations. After this phenomenal and qualitative exploration stage, the students were asked to read the relevant part of the lab book where formal terms and physical quantities were introduced. Importantly, the students were given opportunities to refine their understanding and language by comparing their own explanations with the formal definitions and by answering some conceptual and epistemological questions. Then the students conducted and/or observed more quantitative experiments, built mathematical models, devised testing experiments, and eventually applied the tested models to real-life situations. For instance, to learn the concepts of electrical conductors and insulators, the ISLE students, working in small groups in the laboratory, conducted and observed the following experiments: First, they touched one edge of a foam board (held by a foam cup) onto a negatively charged Van de Graff generator, and then brought the board close to a hanging piece of negatively charged tape. The tape was repelled away by the touching edge but attracted by the opposite non-touching edge. Following this, the students performed a similar experiment with an aluminum pie pan (held by a foam cup). It was observed that the negatively charged tape was repelled away not only by the touching point but all the other points around the whole edge. A common explanation from the students was that “*electric charges are distributed evenly through the aluminum pan material, while for the foam board, only the charged point maintains charge.*” Then they designed their own experiments to test their explanations, using whatever they needed from the given equipment and materials. For a testing experiment [13], the students were required to practice explicitly

hypothetical-deductive reasoning [14]: In their lab notebooks the students needed to write down the model being tested, experimental design, prediction, actual result, and conclusion. After this qualitative inquiry stage, the terms of conductors and insulators were introduced. Then the students applied the concept of conductors and insulators to do more experiments [13] such as charging by induction. (In this case further quantitative experiments were not needed.)

### III. THE INSTRUMENTS AND RESULTS

#### Open-ended convincing questions

To probe students' justification for their knowing and to evaluate the effectiveness of ISLE, “convincing” questions [15] were developed and used (see examples in Figs. 1-2. The question in Fig. 2 was finalized based on think-aloud interviews of three physics students.) After reading a few students' responses to the convincing questions shown in Figs. 1-2, it was clear that they tried to “convince” their peers in a number of different ways. An assumption was made that the way that a student convinced their peers reflected their beliefs about the justification of knowledge. Based on epistemological dimensions identified by others [7, 16] and the epistemological goals of ISLE (e.g., justifying of knowledge based on experimental evidence), the students' justification of knowledge are specified along a continuum as follows:

1. *Naïve knowing*: referring explicitly to the authority (i.e., professor or textbook) or repeating formal definitions, equations, or typical explanations from the authority.
2. *Developmental knowing*: citing an example (which was considered as experimental evidence in the coding), but not illustrating it in detail.
3. *Transitional knowing*: describing one or more examples in detail but without logical interpretation of evidence.
4. *Scientific knowing*: clearly describing an experiment and exhibiting a hypothetical-deductive thinking pattern.

Each student's response was coded following the categories above. (Conceptual mistakes in a student's answer were not justified as a major factor to affect the coding.)

The question shown in Fig. 1 (called the pre-test question) was given to 46 students on a

How would you convince a student in your physics class that the energy is conserved? Clearly write down your answer.

Fig. 1: Pre-test question given to the ISLE students

How would you convince a student in your physics class that electric charges (i.e., electrons) can move freely in an aluminum pie pan?

Fig. 2: Question given to the ISLE students after the first four-week learning cycle

quiz at the very beginning of the Spring 2002 ISLE class. All the students had learned introductory mechanics in an environment integrated with Real Time Physics [17]. Results of this question are summarized in Table 1. After four weeks of ISLE instruction, the question in Fig. 2 was given on the first midterm. Results of students' responses are shown in Table 2. One example of an ISLE student's response, coded as scientific knowing, is shown in Fig. 3.

These results show that a substantial shift was achieved in students' justification of knowledge after being exposed to ISLE for several weeks. The change is favorable, since scientific knowing is valued in ISLE and is more productive in the professional workplace. However, these two questions are context-dependent. The observed change does not necessarily mean that many ISLE students had developed the way of the scientific knowing in

Table 1: Distribution of ISLE students' responses to the pre-test question shown in Fig. 1

Code 1	Code 2	Code 3	Code 4
<b>28%</b>	<b>15%</b>	<b>50%</b>	<b>7%</b>

Table 2: Distribution of ISLE students' responses to the convincing question shown in Fig 2

Code 1	Code 2	Code 3	Code 4
<b>0</b>	<b>0</b>	<b>30%</b>	<b>70%</b>

"...I would place the edge of a pie tin held with an insulated cup on the top of an electroscope. I would then touch the opposite side of pie tin with a negatively charged rubber rod. If the charge are free to move in a conductor, then the negative charge in the rod should pass through the pie tin and move the indicator on the electroscope..."(sic)

Fig. 3: Sample of the ISLE students' responses coded as the scientific knowing

general. The results may indicate that students' naïve epistemologies are made as "context-sensitive resources [6]." The justification of their knowledge may depend on the way they developed the resources in a particular context. In ISLE the student serves as the source of scientific knowledge and the justification of knowledge stemmed from logical interpretation of evidence. In traditional instruction the student receives knowledge from an authority (e.g., the text & professor). In this context, information gathered by experimentation is only valid if it agrees with the authority. So the epistemological messages inherent in the student's content knowledge are different, when the content knowledge is gained in different ways.

How would you convince a student in your physics class that electric charges (i.e., electrons) can move freely in an aluminum pie pan? Please circle one that you think is most convincing.

(a) I would let the student look at the physics textbook. The textbook says that aluminum is a conductor, and a conductor is a material in which electric charges move freely. So in the aluminum pie pan electric charges (i.e., electrons) must move freely.

(b) I would show the student my class notes. In class the professor gave a definition of a conductor is a material that allows electric charges (i.e., electrons) to flow. The professor told us that aluminum is a good conductor. So for sure electric charges (i.e., electrons) can move freely in the aluminum pie pan.

(c) I would ask the student to hold the aluminum pie pan by his hand and to touch the pan with a charged Van de Graff generator. The student will get "zapped" (an electrical shock). So this would show that the aluminum pie pan allows the charge on the generator to flow freely and reach the side of the pan close to the hand.

(d) I would ask the student to bring the aluminum pie pan near a charged object, for example, a hanging glass rod charged positively. The student would observe that the charged object will be attracted to the pie pan. So this shows that electric charges (i.e., electrons) can move freely in the aluminum pie pan. As they are attracted to the rod they move closer to it, making the side of the pan close to the rod charged negatively.

Fig. 4: Question given to both the ISLE and non-ISLE students

### Multiple-choice convincing question

Due to some limits in accessing non-ISLE students, the multiple-choice convincing question shown in Fig. 4 was given to the ISLE students and non-ISLE introductory physics students in the spring of 2003. One of the goals was to probe and compare the naïve knowing of both the ISLE and non-ISLE students. Results in Table 3 indicate that none of the ISLE students still believed the authority (i.e., the text) was the most convincing resource, yet about a quarter of the non-ISLE students did so. Those results are consistent with the findings above. After typical instruction, about 25% of students justify their knowledge by citing an authority. In addition, the results suggest that in the same or similar context the way that students are exposed to the content knowledge may affect their justification of knowledge.

Table 3: Students' responses to the multiple-choice question in Fig. 4

	(a)	(b)	(c)	(d)
ISLE (N = 41)	0	0	34%	66%
Non-ISLE (N = 58)	24%	2%	29%	45%

### IV. IMPLICATIONS FOR INSTRUCTION AND FUTURE RESEARCH

The preliminary results of this study suggest that ISLE helps students not only understand the concepts but also gain the knowledge of the experimental evidence supporting the concepts. In addition, the explicit and tacit epistemological messages inherent in ISLE may enrich students' justification of knowledge in certain contexts. Much research is currently underway to probe the ISLE students' epistemological developments over a whole course and to investigate how the justification of knowledge correlates to conceptual understanding and problem solving.

### ACKNOWLEDGEMENTS

This research is supported in part by NSF grants DUE #0088906 & #0242845. I am grateful for the collaboration with and support of Alan Van Heuvelen, Eugenia Etkina, Kathy Harper, and David Van Domelen. My special thanks also go to the three reviewers for their critical and constructive comments.

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