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The Categorization of Sense-Makers in Introductory Physics

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THE CATEGORIZATION OF SENSE-MAKERS IN INTRODUCTORY PHYSICS

by

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Abstract

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An important part of introductory physics is learning the skill of sense-making or what we call thinking like a physicist. Using survey data, we will perform a cluster analysis to see which categories of sense-making skills are used most often in conjunction with one another. We will be discussing the different strategies that students use as they develop their physics problem solving skills. This analysis will be helpful because it will help professors understand the different levels of sophistication that students must go through to become successful, independent problem solvers.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Introductory physics has a high failure rate compared to other introductory classes. One of the reasons for this high failure rates is that students try many ways to learn and understand physics yet some students never manage to gain mastery of the subject. Nearly all physics problems can be solved in more than one way; similarly, understanding physics can be brought about with many different ways of thinking. Some students focus on only one pathway to understanding and are ultimately unsuccessful in their learning. In this study I have examined different ways students make sense out of physics ideas and problems and what students believe it means to “think like a physicist”.

The focus of this study is to identify the ways of thinking that introductory physics students engage in to make sense of physics ideas and problems, and then to identify groups or archetypes of students based on patterns of these sense-making activities. Identifying these sense-making activities and student sense-making archetypes will lead to instruction to help students engage in more sophisticated sense-making activities, which in turn will increase student success in introductory physics courses and ultimately increase participation in physics and related fields. Particularly in urban settings, like the University of Memphis, significant challenges persist in recruiting and retaining underrepresented groups of students.

In this thesis, I will first discuss the research literature relevant to student sense-making approaches. I will then discuss the methods used to collect and analyze the data and the results of the analysis. Finally, I will discuss the findings and the limitations of the research.

CHAPTER 2

LITERATURE REVIEW

The goal of this study is to understand students' sense-making strategies in introductory physics. Studying these sense-making strategies is important because the primary goal of physics instruction (from the instructor's point of view) is to help students to learn to “think like physicists” (Van Heuvelen 891-897; Reif 17-32). "Thinking like a physicist" involves both having correct understandings of physics ideas and knowing how to make sense of new physics ideas and situations. Trumper says, "thinking like a physicist" involves conceptual knowledge, problem-solving skills, making connections with real world phenomena, and designing and performing experiments to investigate physical phenomena. “To think like a physicist involves an understanding of the scientific methods of inquiry and the ability to use these methods in their own investigations” (Trumper). This study does not include students' experimentation abilities, but rather focuses on how to make sense of new physics ideas and situations.

Studies that compare expert and novice performance show that not only do experts have more domain-specific knowledge than novices, but that experts use their knowledge differently (Chi, Glaser, and Rees 7-75; Hardiman, Dufresne, and Mestre 627-638). Such studies found that experts tend to engage in activities that help them make sense out of the physics ideas or problem situation (like doing a qualitative analysis, constructing a mathematical representation or considering extreme cases), while novices focus on algorithmic or recursive approaches.

Additionally, expert problem solvers tend to spend more time planning their solutions than novice problem solvers (Huffman 551-570). Novices use the equations as a crutch in order to bypass attempts at learning the underlying concepts, and because of this, novice students tend to have very little organized structure to their knowledge. Rather, they have a mix of random facts and equations with no concepts attached to them (Van Heuvelen 891-897). Other students may be able to grasp at the concepts but a full understanding and fluency with the terms and ideas may not be present. Hammer states, “students who have not developed ‘abstract’ reasoning are seen as incapable of understanding the concepts of physics, such as *force* or *energy*, because these are not directly observable, manipulable objects” (Hammer 1316-1325).

Other factors, like a student’s self-efficacy in physics, interest in physics, and expectations about learning physics, may also affect the physics student’s performance. If a student believes that she cannot “do” physics, it may negatively impact her confidence and abilities with the topics. Hazari et al. reports, “students’ interests, motivations, and beliefs about themselves have a far-reaching impact on their persistence and participation in science” (Hazari et al. 978-1003). Students with “motion interests” (riding rollercoasters, skating, or aviation for example) may be able to make more connections with the concepts because of their real life experiences. Students’ beliefs about the “right way” to think about and learn physics will influence how they approach the material in the course. Hammer says, “how students reason in a physics course may reflect not only whether they have or do not have certain abilities, but also what they believe about the course and the knowledge and reasoning it will entail” (Hammer 1316-1325).

Conceptual misunderstandings negatively impact student’s performance as well. All students bring unexamined understandings and experiences to their introductory physics courses. Some of these unexamined understandings are in disagreement with scientific conceptions and may be characterized as “misconceptions”. Hammer states, “from the misconceptions perspective, students are not simply ignorant: They have knowledge about the physical world; their knowledge is reasonable and useful to them; and they use that knowledge to understand what they hear and see” (Hammer 1316-1325). One concept that can make students question their previous knowledge is Newton’s second law of motion as it relates to a horse moving a cart. They know that Newton’s third states that every force has a paired force that is equivalent in magnitude and opposite in direction, yet the horse should not be moving the cart if they have equal forces on one another. The student neglects the force of friction between the horse hooves and the ground compared to the friction between the wheels of the cart and the ground. By focusing on Newton’s third law they are neglecting to look at the whole system which can make them question their intuition.

By approaching students a different way with the problem statement we may put more of an emphasis on concepts instead of the math. Van Heuvelen says, “instead of thinking of a problem as an effort to determine some unknown quantity, we might instead encourage students to think of the problem statement as describing a physical process--a movie of a region of space during a short time interval or of an event at one instant of time" (Van Heuvelen 891-897). By using this approach, we may steer students away from their reliance on rote memorization of equations, which can prove unreliable in times of stress. Providing students with certain techniques to solve problems may improve their success rates. Huffman says, "one instructional method that has been used to address both problem-solving performance and conceptual understanding is explicit problem-solving instruction. Explicit problem solving is instruction that directly teaches students how to use more advanced techniques for solving problems" (Huffman 551-570). The explicit problem-solving techniques lay out a very precise way of solving every problem that explores in depth the student's understanding of the concept. Huffman also states, "students who learn the explicit problem-solving strategies exhibited more advanced problem-solving performance, including better qualitative descriptions of problems, more extensive planning, and more complete solutions" (Huffman 551-570).

CHAPTER 3

METHODS

This section will describe the methods used during the cluster analysis as well as during the interviews. The data analysis was completed using SPSS19.

Survey Data

In Spring 2011, a survey of the attitudes and sense-making habits was administered online to two classes of introductory calculus-based physics (n=63 students): one Introductory Mechanics class and one Introductory Electricity & Magnetism class. The questions on the survey included open-ended questions that probed the students' views about physics and their approaches to learning physics (see Tables 3.1-3.5) as well as the Likert-scale items of the Colorado Learning Attitudes about Science Survey (CLASS). The survey was administered during the last week of instruction and extra credit was awarded in the course for completing the survey.

Table 3.1 Summary of data sources

Term	Data Set	n
Spring 2011	Survey of Physics Views (used in cluster analysis)	63
Spring 2013	Background & Views Survey	17
Spring 2013	Views Interviews	5
Spring 2013	Problem-Solving Interviews	2

The students' responses to each open-ended survey question were coded for analysis. The coding process started with an open coding by two independent coders. The unit of analysis was an individual student's response to a question on the survey. Each response was assigned only one code. The codes from each coder were then compared and preliminary code assignments were refined through discussion. The survey responses were then recoded by both coders using the refined coding scheme, achieving an inter-rater reliability of 73%. All disagreements in code assignment were resolved through discussion. The codes for each question and a description of these codes are included in Tables 3.2-3.6. The distributions of answers to each question are shown in Figures 3.2-3.6.

Table 3.2 Codes and examples for the survey question: “What do you think ‘thinking like a physicist’ means?”

Code	***Definition of Code***	***Example from Student***
Thinking logically and empirically	Student has a set process that is ordered and logical in nature.	“Identifying the knowns and unknowns and using the given tools the solve for the unknowns.”
Concepts not specific situations	Student understands the underlying concepts in a problem	“Looking at a problem, and trying to understand the underlying principles that govern it.”
Thinking comprehensively	Student thinks of everything involved to solve problem.	“Taking all parts of the topic into consideration and observing the material with an open mind.”
Find the why of the problem	Student tries to find why a problem works the way it does.	“trying to understand why something is rather than how something does something”
Multiple thought tracks	Student uses different types of problem-solving techniques to solve a problem.	“The ability to look at the problem from all ends and determining which method is the best way to solve the problem at hand.”
Break problem into parts	Student breaks problem into smaller parts to work through.	“Analyzing a problem by parts, and not basing any of your ideas on what seems like the most likley outcome.”
Other	Student does not report a thinking skill.	“E=mc^2 :)”

Table 3.3 Codes and examples for the survey question: “When you are thinking about a physics problem and you get stuck, what do you do to try to get unstuck?”

Code	***Definition of Code***	***Example from Student***
Reread book, notes, problem	Student uses the book, notes, or other resources to find help.	“I refer to my text book or I research on the internet.”
Start over or back track through problem	Student starts over completely or backtracks to where they are sure of their approach.	“Erase everything I have written down, and start over.”
Look for similar examples	Student looks for an example similar to the problem they are working.	“I try to look at other examples that may be worked out in other resources.”
Draw a picture	Student draws a picture to try and see the problem situation.	“write out all the numbers, variables and draw a diagram”
Find useful equations	Student tries to find an equation to use.	“Write down what I have and need as well as possible equations to use”
Check for errors	Student goes back through work to check for errors.	“Rework the problem and check my math for discrepancies.”
Multiple strategies, context dependent	Student uses multiple strategies to get unstuck or reports on a specific problem.	“Check units, glance at my picture, see if the givens match any equation I know.”
Ask friend or tutor	Student seeks help from another human.	“I ask a friend or tutor”
Skip or abandon problem	Student gives up on problem or skips it to return at a later time.	“My brain freezes so I can't seem to get past that part and unfreeze it.”
Use what you know	Student looks at what they know to get started.	“Write all given information out and try to find a correlation”
Ask for help or start over	Student asks for help or starts from a part in the problem they were comfortable with.	“if i get stuck i will either ask for help or start the problem over at either a part i know is right or the entire problem itself.”
Other	Student reports a nonspecific approach.	“Google it.”

Table 3.4 Codes and examples for the survey question: “When you work on physics problems, what kinds of reasoning/thinking do you do now that used to be difficult for you?”

Code	***Definition of Code***	***Example from Student***
Visualizes problem	Student draws a picture or tries to visualize the problem or concept.	“Physics in still hard for me but I know always try to draw or visualize a picture of the problem at hand.”
Break into components	Student breaks everything down to see its components or force diagram.	“Look at the overall picture first and then break everything down into components”
Uses coordinate systems	Student works out the geometry of the situation.	“It is much easier for me to set x and y components of forces equal to each other, and I am better at using trigonometric identities, although I still have some trouble.”
Read/make sense of the question	Student figures out what the problem gives them and what it is asking for.	“Well I double check and make sure I read the question right. Most of the time there are specific hints in most physics questions that help you solve the answer that you are looking for.”
Broader process described	Student talks about a specific process they go through now.	“Now, before beginning any calculations, I try to think about the mechanics of the situation and predict what should logically happen, so I have a rough estimation to check my final answer against.”
Reasoning with units	Student uses the units to check for accuracy.	“When given a problem with many variables I think about how the units work out in the final answer. Are the units of my answer and the units Im supposed to be getting equal?”
No change	Student does not report any change in reasoning.	“I still do the same thing I think. Imagine the problem, relate it to laws and ideas and then start solving it”
Specific physics/math topics	Student reports a very specific situation they improved on.	“Calculations in banked curves and circular movement.”

Table 3.4 continued

Code	***Definition of Code***	***Example from Student***
Other	Student does not report a definable reasoning skill.	“Gathering of all information related to the problem”

Table 3.5 Codes and examples for the survey question “How do you know when you understand an idea in physics or a physics problem really well?”

Code	***Definition of Code***	***Example from Student***
Can work a problem straight forwardly	Can work a problem without referring to something else or asking for help.	“When I am able to work a problem, similar to an example, on my own without having to refer to reference material.”
Ability to explain to self or others	Student can explain the concept or problem to others.	“When I can teach or explain that concept to someone else confidently, I know it well.”
Gets correct answer	Student bases understanding on correctness of solutions.	“As soon as the online homework said I had the correct answer.”
Lack of confusion/it just "clicks"	The student understands the concept without struggling.	“When the equations are clear to me and there is not much confusion in how the equations should be used.”
Understand the concept	Student understands the underlying concepts in a problem	“When you take a test or do the homework and understand how to use the concepts and reasoning”
Understanding the problem situation	Student can easily understand what the problem is asking for.	“When I can read a problem and know what its asking for and what ideas to apply.”
Other	Response did not fit into other categories.	“My steps during the problem solving process are neat and ordered. Ive noticed my handwriting is even bettter... Wierd”

Table 3.6 Codes and examples for the survey question “When learning a new topic or idea, what kinds of things do you try to do in order to get a good understanding?”

Code	***Definition of Code***	***Example from Student***
Remember/map known information to equation	Student works through what the different variables are in an equation.	“If it is equations, I learn what each symbol or letter means and I write it the long way and the short way everytime I use it until I get it down pat.”
Solve practice problems	Student solves many problems to try to gain mastery.	“I try to go over as many practice problems as possible, but first I go back and go over and try to have a clear understanding on the new topic or idea.”
Make connections/ comparisons to real world experiences or familiar topics	Student compares physics concepts to things they have experienced previously.	“I look for the links, comparisons, and differences between old material and new.”
Learning about the equations (when to use or how to derive)	Student learns how the equations work in order to gain mastery.	“I try to learn the formula and understand why it works and how it works.”
Listen, read materials, watch videos, take notes	Student pays attention to lecture, notes, and online videos in order to gain mastery.	“listen to the teacher's lecture because it is usually more helpful and informative than trying to learn the material on my own.”
Read and solve problems	Student reads through notes or the book and then solves problems.	“I try to read and comprehend the subject. I then go through and solve some problems involving that subject.”
Multiple strategies/approaches	Student uses more than one approach to mastery.	“I try to relate a new equation to perhaps an older equation learned. I also reread the text within the book and the slides within class to help get to views on the same new concept.”
Other	Response did not fit into other categories.	“I repeat the idea to myself in my head.”

Sections of courses with two different professors were used for this research. The cluster data and some of the interviews were from one professor, whereas only interviews came from the second professor. The first professor uses powerpoints which can be directly edited during the class for the lecture parts of the course and posts the powerpoints online for student access. The second professor uses direct lecture and writing notes on the board for the course. Both sections of students have the same instruction for the laboratory part of the course. The data for the classes came from both an introductory mechanics course and from an introductory electricity and magnetism course. The interviews were all from an introductory mechanics course.

Cluster Analysis

The coded students' responses were used to identify groups of students with similar sense-making activities. To identify these groups, an initial cluster analysis was performed using SPSS 19. First, we determined the optimal number of clusters by examining the Scree plot (Figure 3.1) and looking for discontinuities in the first derivative of the curve. This method indicated that the optimal number of clusters for the data set is four. The cluster analysis was repeated, prescribing the number of clusters to be four. This cluster analysis produced a dendrogram which shows the connections between each student and forms an overall tree of relation for all students. By looking at the resulting dendrogram (Figure 3.2) we were able to identify the four clusters of students. Each cluster is a group of students with similar answers to the survey questions. The dendrogram in Figure 3.2 shows which students, as indicated by their identification numbers, are grouped together in each cluster. Typically, as clusters grow, the level of similarity between members of a cluster decreases at an increasing rate. For our data, however, we see levels of similarity decrease at a decreasing rate. Instances of decreasing dissimilarity as clusters grow are called *inversions*. Morgan and Ray say, “there are examples for which inversions do not pose a serious problem, inversions may indicate areas of similarity where there is no clear cluster structure” (Morgan and Ray 117-134). Although some statisticians address these as problem areas, because of the content of our analysis these inversions are not an issue since we can show a cluster structure is not being imposed on the data. By looking at the students within each cluster and their answers we can see that there is a cluster structure present and it is not being forced upon the analysis.

Once the clusters were identified, we then looked at the patterns of responses given by the students within each cluster and compared the response patterns across clusters. Descriptions of the clusters are included in the Results chapter.

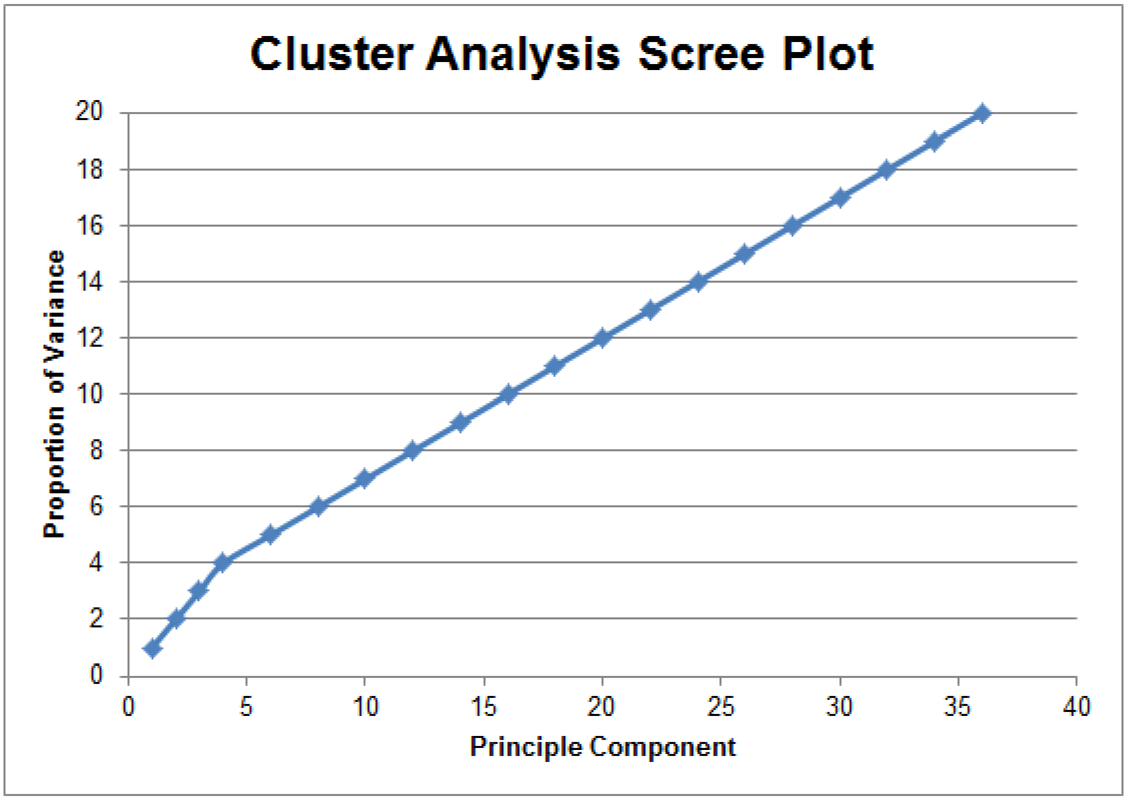

Figure 3.1 Discontinuity in the first derivative of the scree plot used to determine optimal number of clusters.

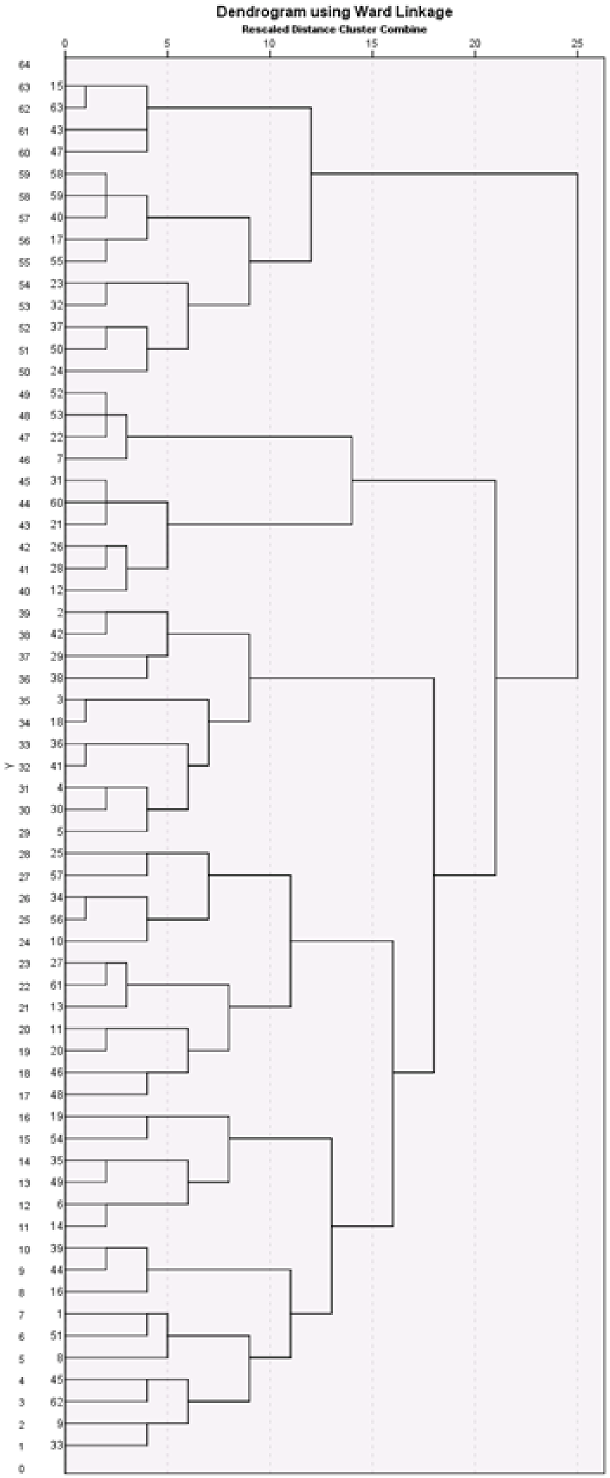

Figure 3.2 Dendrogram of cluster analysis. The outer vertical axis is the number assigned to each student by SPSS during the cluster analysis. The inner vertical access is the identification number assigned to the students by the researcher for analysis. The horizontal axis is the rescaled distance between clusters indicating the degree of similarity.

Interviews

To further understand the results of the cluster analysis, two sets of interviews were conducted in Spring 2013. These students were not the same students whose survey results were used in the cluster analysis. The first set of interviews ("Views" Interviews) focused on the students' views about physics and learning physics. During this first interview, I hoped to identify specific types of sense-makers who might then be invited for a second set of interviews where students solved physics problems ("Problem-Solving" Interviews).

All of the interviews were audio recorded and the individual problem-solving interviews were video recorded in order to be able to capture the students' problem-solving methods. Transcriptions of the audio/video recordings and written interview artifacts were made anonymous and pseudonyms were assigned to protect the confidentiality of the students. There were only two students from the Views Interviews willing to participate in the individual problem-solving interviews. Only one of those interviews yielded enough data for analysis.

Interviews about Students' Views

Potential participants for the Views Interview were identified through a survey of both (a) the student's academic background in physics and (b) the student's views about physics and learning physics. The survey was administered online to students in different sections of the calculus-based introductory mechanics class, including two non-honors sections (n=38 and n=94 with different instructors) and one honors section (n=9). These students were typically freshmen and sophomore science and engineering majors. Survey participants were recruited during class for each lecture section of the course. The instructors were not present during recruitment. The students who were interested in participating were asked to write their names and email addresses on a sign-up sheet. Interview participants were recruited from these survey participants. Interviews were scheduled through email. Students were asked to provide their availability and interviews were scheduled for times when the most students within each group could attend.

The survey contained questions about the student's previous physics courses, the CLASS items, and other open-ended questions related to studying physics. During analysis, the CLASS items were grouped into sense-making items and other items. For each student, the CLASS survey questions were coded as to whether they were favoring expert or novice like answers. This allowed us to check for the students' expert favorability. For each section, the students' favorability on sense-making items were plotted against their favorability on other items (see Figures 3.3-3.4). This plot allowed me to group students during the Views Interviews based on their overall sense-making sophistication. Students in the same sense-making range were invited to participate in the Views Interviews together.

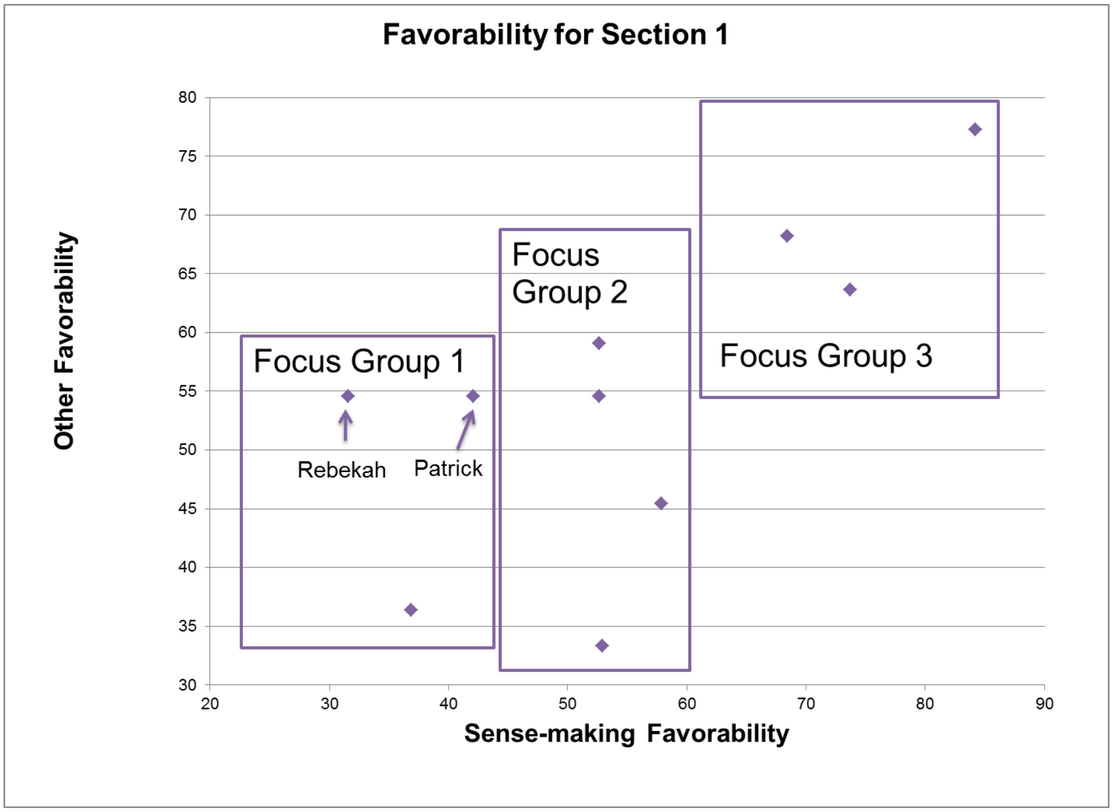

Figure 3.3 CLASS data for Section 1 plotted as favorability on sense-making related items vs. other CLASS items. Purple boxes indicate students who were invited to participate in focus groups together.

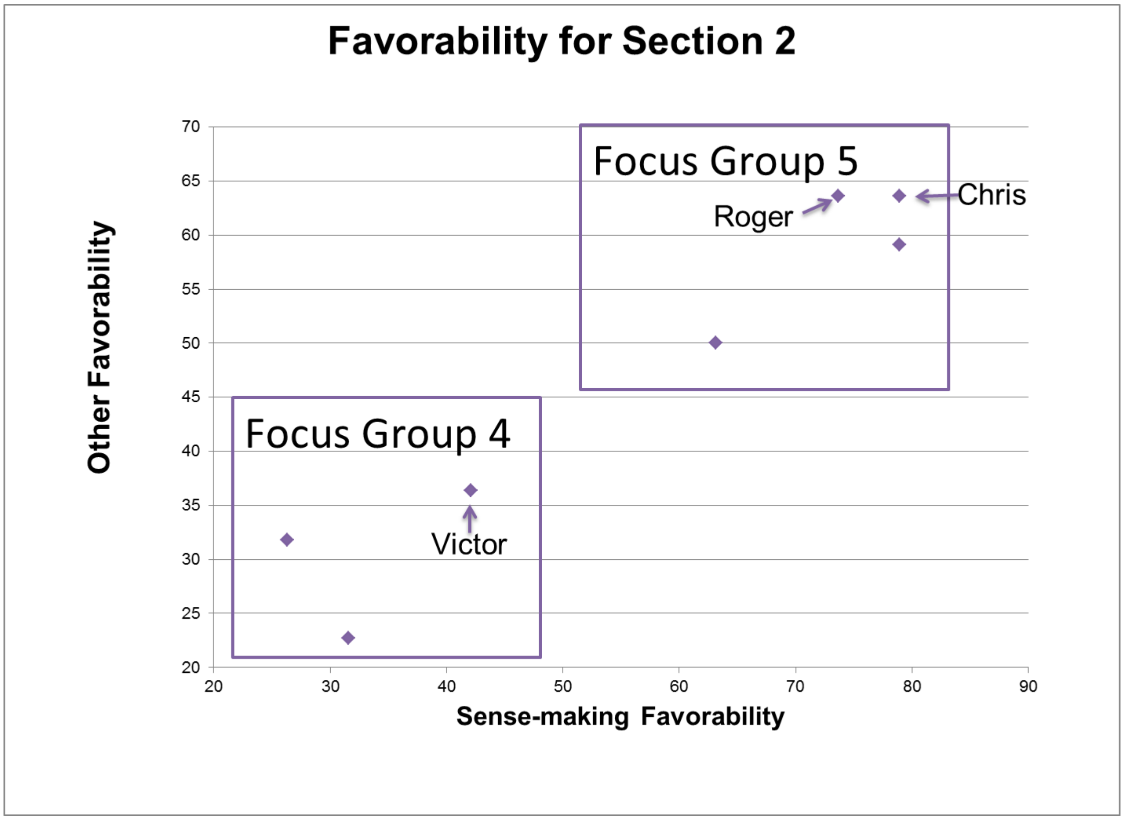

Figure 3.4 CLASS data for Section 2 plotted as favorability on sense-making related items vs. other CLASS items. Purple boxes indicate students who were invited to participate in focus groups together.

The Views Interviews included 5 students with 1-2 students in each interview. The “Views” Interviews took place toward the middle of the semester, just after the students’ spring break. The timing of these interviews was chosen so that students who had never taken a physics course previously would have some experiences in their current course to discuss. I intended to have 5 or 6 student View Interviews (a total of 15-25 students)~~.~~ In the end, I conducted 4 interviews with a total of 5 students participating (Figure 3.5). Student participation may have been low due to students dropping the class, students feeling that their performance in the class was inadequate, a lack of adequate incentive to participate (students were neither paid nor given course credit), or problems with the recruitment procedure (such as students not checking their school email on a regular basis). The Views Interviews were intended to have students from approximately the same level of novice/expert favorability based on the CLASS but only one or two from each group was willing to participate. This allowed students to be on a similar level of sense-making sophistication with other students. It was hoped that students grouped with similar students would be more likely to expound upon the comments during the discussion.

The Views Interviews focused on the following questions so that students could elaborate on their responses to the survey questions:

- When you are learning a new topic or concept, how do you get yourself to understand? What kind of things do you do to learn the topic?
- When you work on a physics problem what sorts of things do you do to figure out how to start working on that problem?
- When you are thinking about a physics problem and you get stuck, what do you do to try to get unstuck?

These types of questions led to the students being identified as different types of sense-makers. These characterizations are discussed in the Results Chapter. Some of sense-making differences I looked for included:

- Relating problems to the real world vs. focusing on specific problem situations with no reference to the real world

- Preferring to plug in numbers before doing algebraic manipulations vs. doing algebraic manipulations with letter symbols
- Searching for equations vs. applying concepts
- Searching for similar examples to a problem vs. applying concepts
- Memorizing solution steps vs. understanding the decisions that need to be made for solving a problem.

This list merely illustrates the extreme ends of each of these aspects of sense-making; real students are expected to fall somewhere along these continua.

Individual Problem-Solving Interviews

Based on these group Views Interviews, a subset of students were asked to participate in individual Problem-Solving Interviews. The Problem-Solving Interviews took place after the Views Interviews had been completed. For these interviews, students were asked to bring two problems with them from class: one question they were comfortable solving and one problem they were struggling to solve. They were also asked to solve a third problem that was posed by the interviewer and was common to all interview participants. The students were asked to “think aloud” while solving the problems.

Each problem-solving interview was analyzed individually. I listened to and transcribed each interview. I then looked for evidence of the students’ sense-making activities. A student’s statements during the interview helped me to locate each student’s sense-making activities on the continuums of differences listed above and helped me to develop a framework for characterizing future students as a certain type of sense-maker. These characterizations are discussed in the Results chapter.

CHAPTER 4

RESULTS

Patterns from Individual Survey Questions

Here I present the categories found among the students’ responses to the individual survey questions administered in Spring 2011. These responses were included in the cluster analysis (see Figures 4.1-4.5).

“Understanding” physics means working problems correctly

Thirty-five percent of students reported their understanding of an idea in physics was based on their ability to work a problem without help or looking back at notes. Eighteen percent of students know they understand a physics topic when they can explain it to someone else or themselves. Sixteen percent of students say they use their understanding of the concepts as a way of measuring their understanding. Thirteen percent of students believe if they can get the correct answer they must understand the concept. Eleven percent of students said they knew they understood the ideas when things just “clicked”. Three percent of students reported their understanding was based on being able to understand the situation of a physics problem.

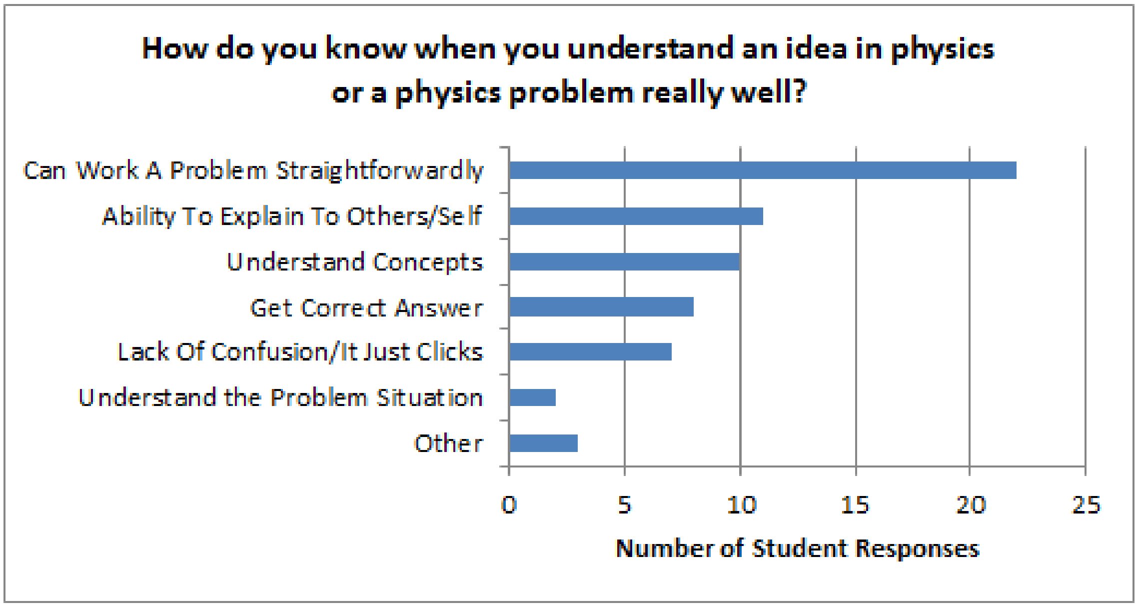

Figure 4.1 Histogram of student responses to “How do you know when you understand an idea in physics or a physics problem really well?”

Thinking-Like-A-Physicist means thinking comprehensively about a physical situation

Twenty-one percent of students defined the thinking of a physicist as thinking comprehensively, that is, thinking about everything involved in a problem. Examples of these responses include: “Accounting for all of the universes properties when thinking about how to solve a problem," and “I think that thinking like a physicist means just thinking about every object that can affect your system and ways to solve them or go around them without them affecting your result.” Both students who thought “thinking like a physicist” mean thinking logically and empirically and those who think it means finding the “why” of the problem numbered about 14%. Those who thought “thinking like a physicist” meant to understand the underlying concepts or use multiple tracks to solve a problem numbered 13% each. Six percent of students reported that a physicist would break a problem into smaller parts to solve it. Nineteen percent of students gave an ambiguous or a vague response. Examples of this include, “Thinking like [the course instructor]” and “Thinking in a different manner than a computer scientist.”

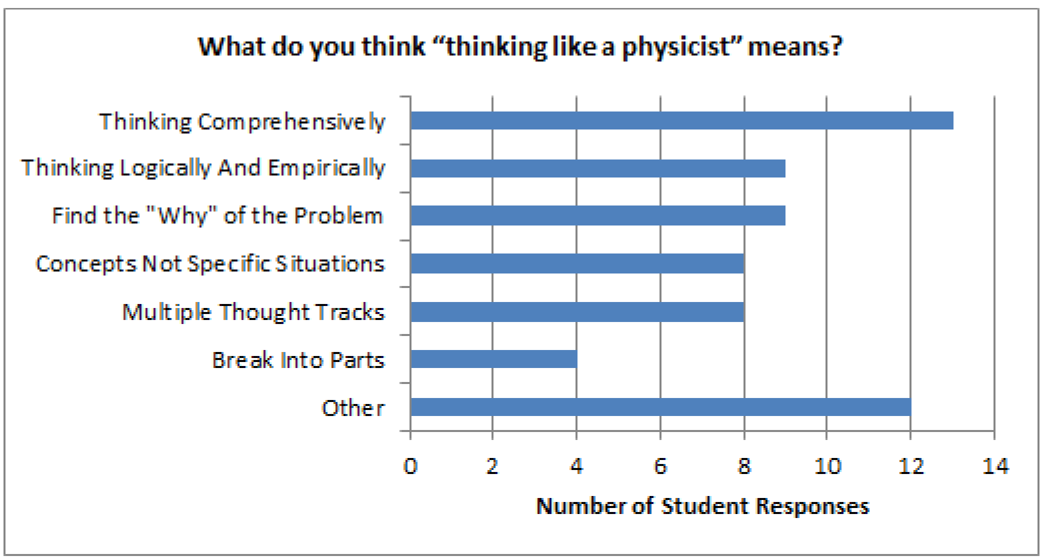

Figure 4.2 Histogram of student responses to “What do you think ‘thinking like a physicist’ means?”

“When learning a new topic or idea, what kinds of things do you try to do in order to get a good understanding?”

Twenty-six percent of students attempt to gain mastery of physics topics by listening in class, taking notes, reviewing notes and book and watching videos. Twenty percent of students do many practice problems in order to grasp the concepts involved. Nineteen percent make connections with the real world and their everyday lives in order to get a good understanding. Another 8% gain mastery by reading the book and solving problems. Almost 5% of students attempt to gain mastery of physics concepts by learning about the equations, either: what the variables in the equation mean, the conceptual meaning of the equation, or how the equation was derived or is connected to other equations. Interestingly, none of the students discussed “knowing the conditions for which an equation is valid” as important for learning about equations. Another 5% of the students reported using multiple strategies to gain mastery of physics. The other 9% of students had other responses such as, “I repeat the idea to myself in my head.”

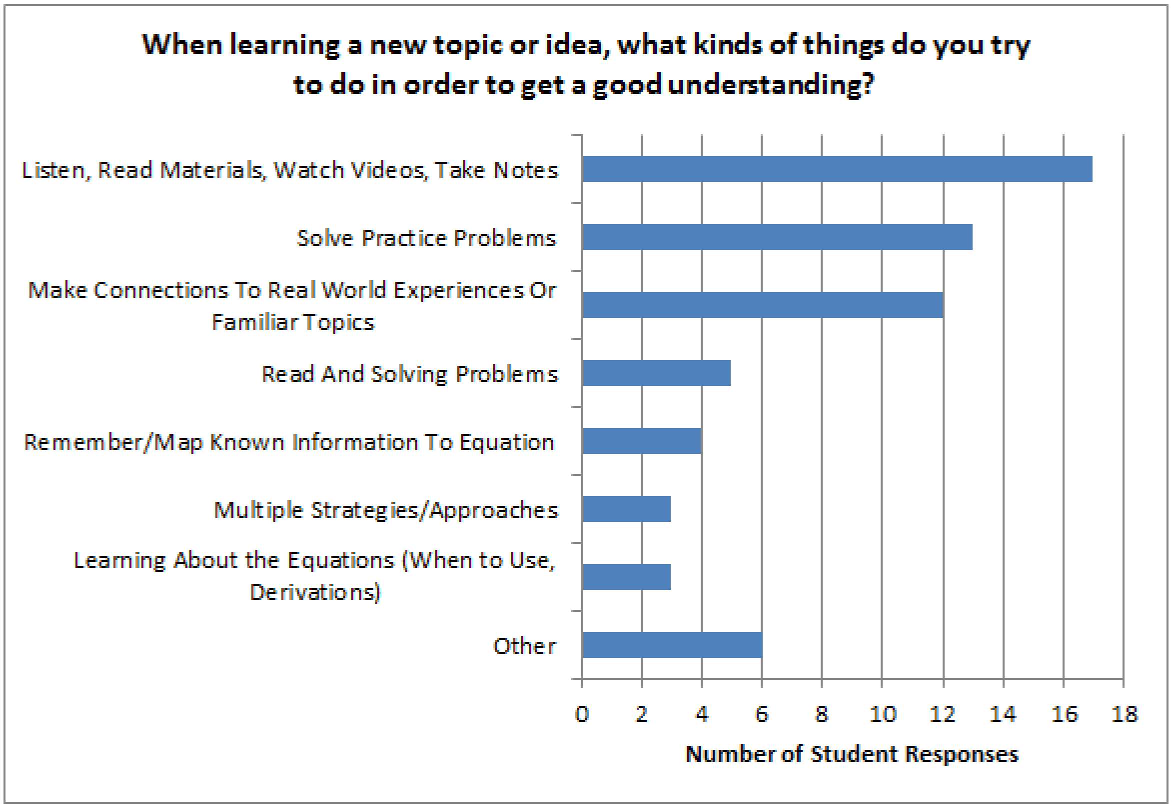

Figure 4.3 Histogram of student responses to “When learning a new topic or idea, what kinds of things do you try to do in order to get a good understanding?”

Students become “unstuck” by reviewing materials

Twenty-one percent of students said they get “unstuck” by rereading the notes, book, or rereading the problem statement. Another 19% number of students reported that they get “unstuck” from a problem by finding a useful equation. About 13% of students answered that they have multiple strategies for getting unstuck or reported how they get unstuck from a certain type of conceptual problem. An example of multiple strategies is, “Go back to the book and reread the sections most pertinent to the problem, then rework the examples most pertinent to the problem. Redraw all of the initial diagrams. Worst case - start over with a new piece of paper so that I don't see the previous attempt.” An example of certain type of conceptual problem is, “I draw a picture, and for force problems, I draw a force diagram, and think about what forces are equal to each other. For problems with an initial situation and a final situation, I think about the velocity, acceleration, etc. at the initial and final situations, and how they relate.” Starting the problem over, looking for similar examples, checking for errors, and students using what they know each held 8% of the student responses. Six percent of students reported that they skip the problem if they get stuck on it. Only 3% of students try drawing a picture to get unstuck from a problem. Only 2% of students reported asking a tutor or friend. This may suggest a lack of networking among students in the early physics courses or that students don’t view peers as legitimate resources to report. The last 2% (one student) reported, “Google it.”

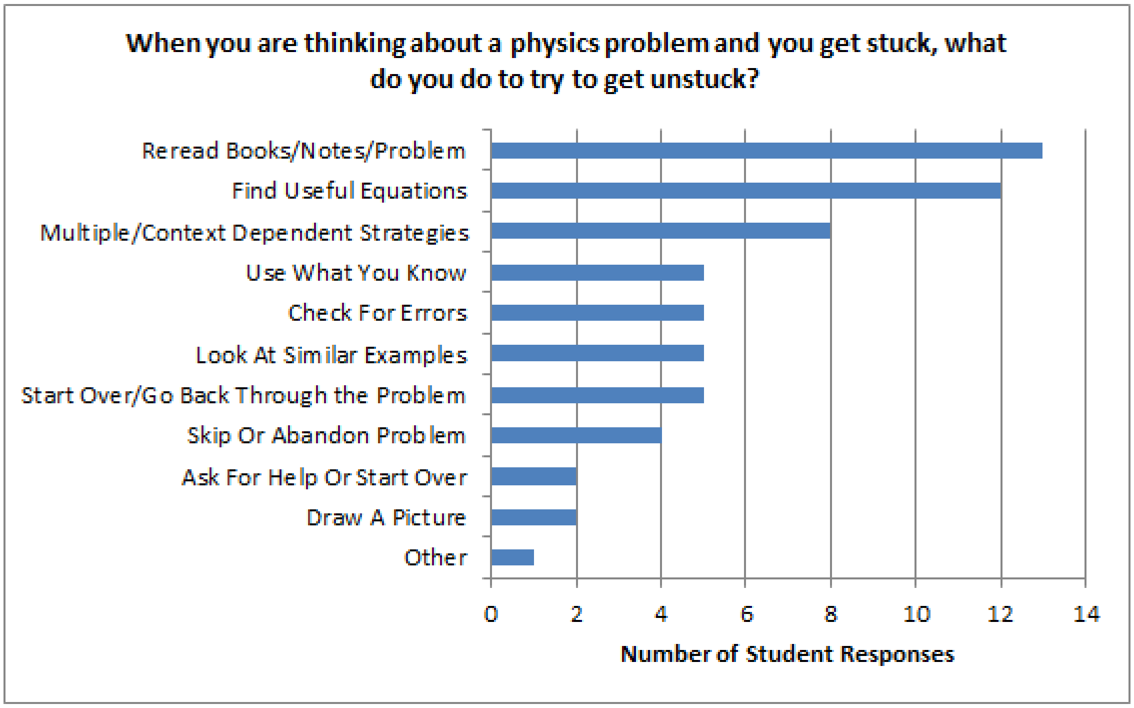

Figure 4.4 Histogram of student responses to “When you are thinking about a physics problem and you get stuck, what do you do to try to get unstuck?”

Visualizing situations and understanding problem statements are new reasoning skills for physics

Twenty-four percent of students report their new reasoning skill as being able to visualize the problem. Most of these students specifically mention drawing a diagram to be able to visualize the situation. Nineteen percent reported they are now able to reason and make sense of the question being asked. Eleven percent of students are now able to break the system into its components to solve the problem. Ten percent reported on a specific concept or topic that they are better at now than before the course. Another 8% reported on a specific process they use that has improved. Five percent of students reported being better at using coordinate systems. Only three percent of students responded they were able to check the units of the problem to make sense of the situation. About 10% reported that they had no change in their reasoning. Another 11% had other answers such as, “I am able to calm down and really look over the problem now. Before if I didn't know the answer or where to start I would start to panic, now I feel I am able to think calmly through the problem and get the correct answer.”

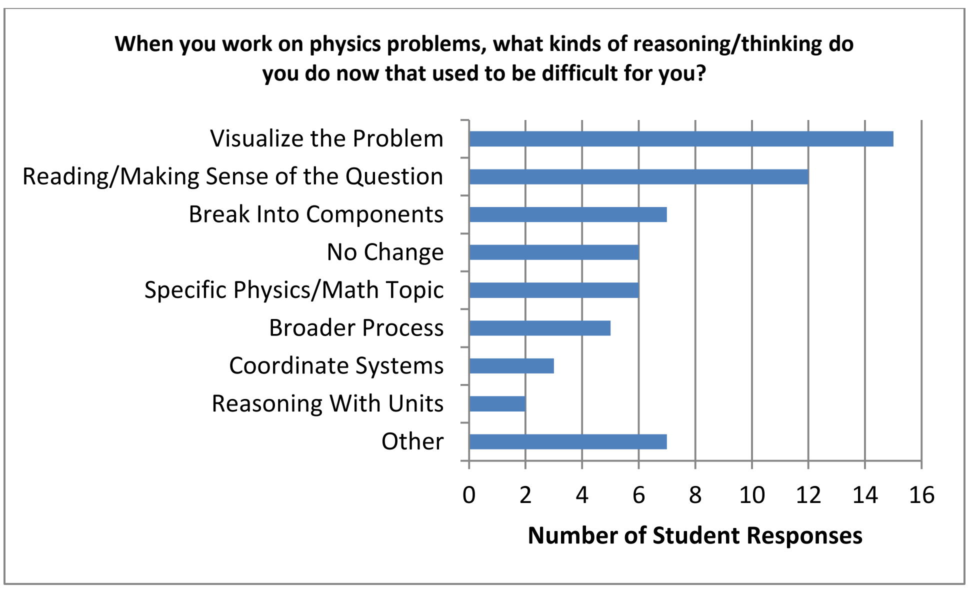

Figure 4.5 Histogram of student responses to “When you work on physics problems, what kinds of reasoning/thinking do you do now that used to be difficult for you?”

Student Clusters from Cluster Analysis

The cluster analysis reveals patterns among students across individual survey questions. Here I describe the general characteristics of students who are grouped together in sense-making clusters.

Cluster 1 - Conceptual thinkers

The students in Cluster 1 (n=14) gave responses that are more focused on conceptual understanding compared to the other clusters. Students in Cluster 1 mostly believe that "thinking like a physicist" means to think comprehensively about a problem situation. They also believe that they know when they understand a physics idea or topic really well when they understand the concepts or are able to solve problems straightforwardly. 43% of the students in this cluster believe the best things to do to understand a problem are to listen, read materials, watch videos, and take notes. Many of these students, when they get stuck on a problem, start the problem over, skip the problem or try rereading notes, the book, or the problem statement. An example of a student's answer is, "Reread the problem, conceptualize it a different way. Go through the chapter and try to see the variables in an equation in the sample problems in the chapter. Talk through it and convince myself that the way I was thinking is correct."

Cluster 2 - Problem-oriented sense-makers

Cluster 2 (n=10) contains students who rely on using materials to understand or get unstuck from a problem, and they base their knowledge and understanding on their ability to solve problems. All of the students in this cluster believe the best way to go from stuck to unstuck with a problem is to reread the book, notes, or the problem. Students in Cluster 2 report their learning and new reasoning as being mostly from reading books, notes, or problems. Over half of them said that one of their new reasoning skills was to read and make sense of the problem. Students report examples of making sense of a problem are learning to approach the problem, figuring out what the problem is asking for, or just thinking about the problem. A few of them believed that the way to measure understanding was whether or not they got the answer to a problem correct. The students in cluster two are more problem-oriented than students in other clusters.

Cluster 3 - Real-world users

Cluster three contains the students who made connections to their everyday lives and experiences to help them make sense of the physics concepts. Cluster 3 contains 11 students that base their understanding on their perceptions of the world around them and success in solving problems. The majority of the third cluster believed that they know when they understand a physics topic well when they are able to solve problems straightforwardly; this was the most common answer for that particular question. Seven of them believed that the way to bring better understanding is to make connections to real world events or familiar topics. For new reasoning skills, the only students who mentioned learning more about coordinate systems were found in Cluster 3. One example of this type of answer is, “It was extremely awkward, especially at first, to get used to a non-Cartesian (or variable Cartesian) [*meaning rotated,* *rectangular*] coordinate system -now I am more comfortable with having various signed directions of movement and x/y axes that may not be strictly horizontal and vertical." Cluster 3 contains all but two students who make connections to the real world or familiar topics, with the other two cases being in cluster four.

Cluster 4 - Other sense-makers

Cluster 4 contains all the students that do not fit in other clusters a total of 28 students. The most common way to get "unstuck" reported by these students (12 out of 28 students) was to find a suitable equation to use. All other patterns of responses included less than 30% of the group. Cluster 4 is the only cluster containing students who find an appropriate equation to get unstuck and contains all but one of the students who "uses what they know" to become unstuck. An example of a student reporting they look for an appropriate equation is, "I write down all knowns and unknowns and any formulas related to both. Then I see where there is any overlapping." The only cases of students indicating a specific process as new reasoning were found in cluster four. Cluster four is the only cluster containing students who reported understanding the problem situation as a means of measuring understanding.

Responses found across all clusters

One similarity among the clusters is that all the clusters contain both students who solve lots of problems and students who review their materials as a way to understand the concepts. The students who indicated visualizing as a new reasoning skill are found in all four clusters. All four clusters contained students who based their perception of their level of understanding on being able to get an answer straightforwardly.

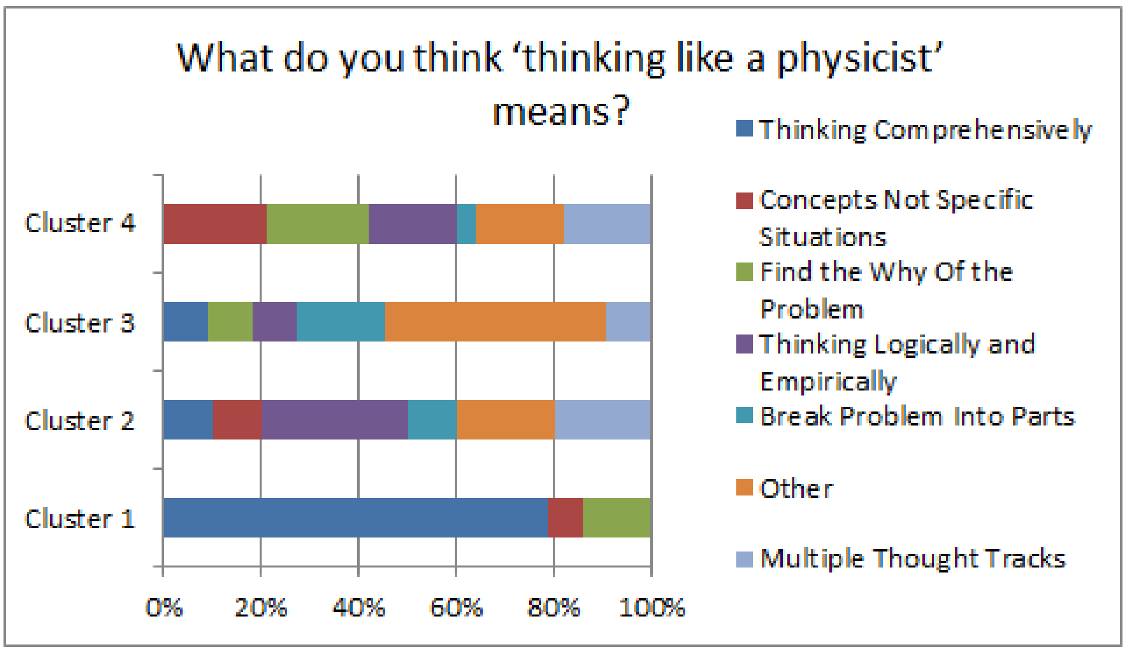

Figure 4.6 Percentage of codes in each cluster for "What do you think "thinking like a physicist" means?

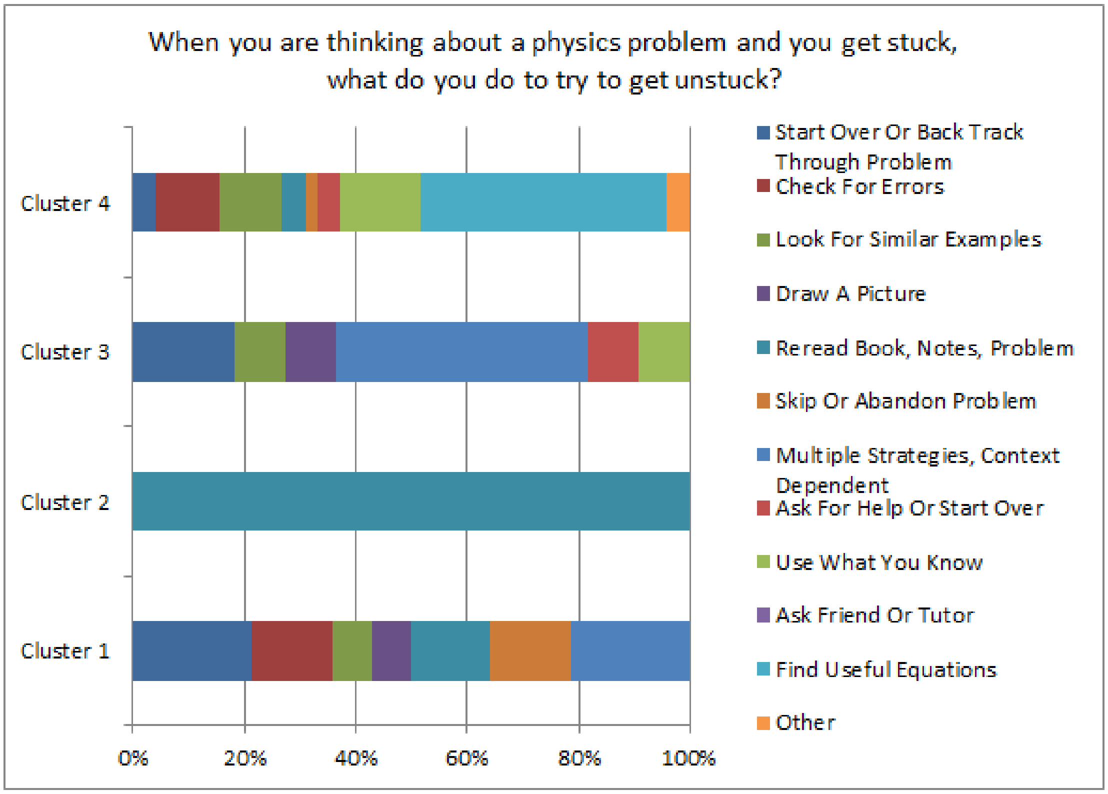

Figure 4.7 Percentage of codes in each cluster for “When you are thinking about a physics problem and you get stuck, what do you do to try to get unstuck?”

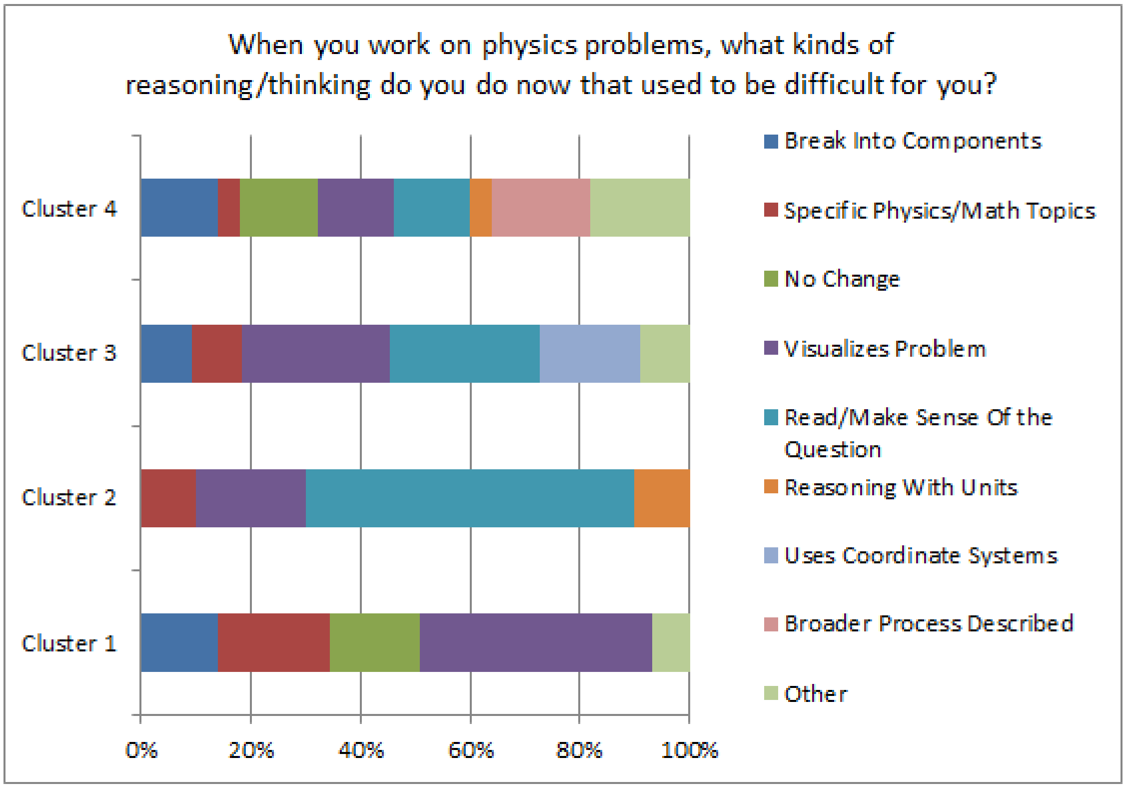

Figure 4.8 Percentage of codes in each cluster for “When you work on physics problems, kinds of reasoning/thinking do you do now that used to be difficult for you?”

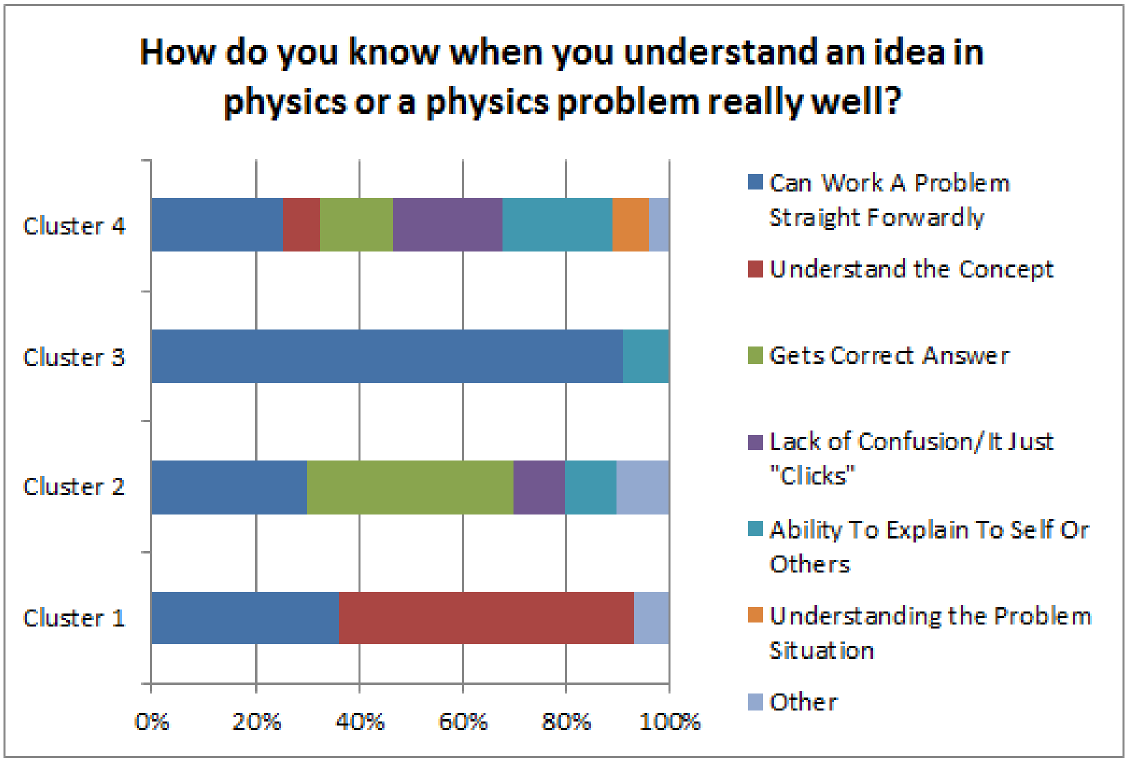

Figure 4.9 Percentage of codes in each cluster for “How do you know when you understand an idea in physics or a physics problem really well?”

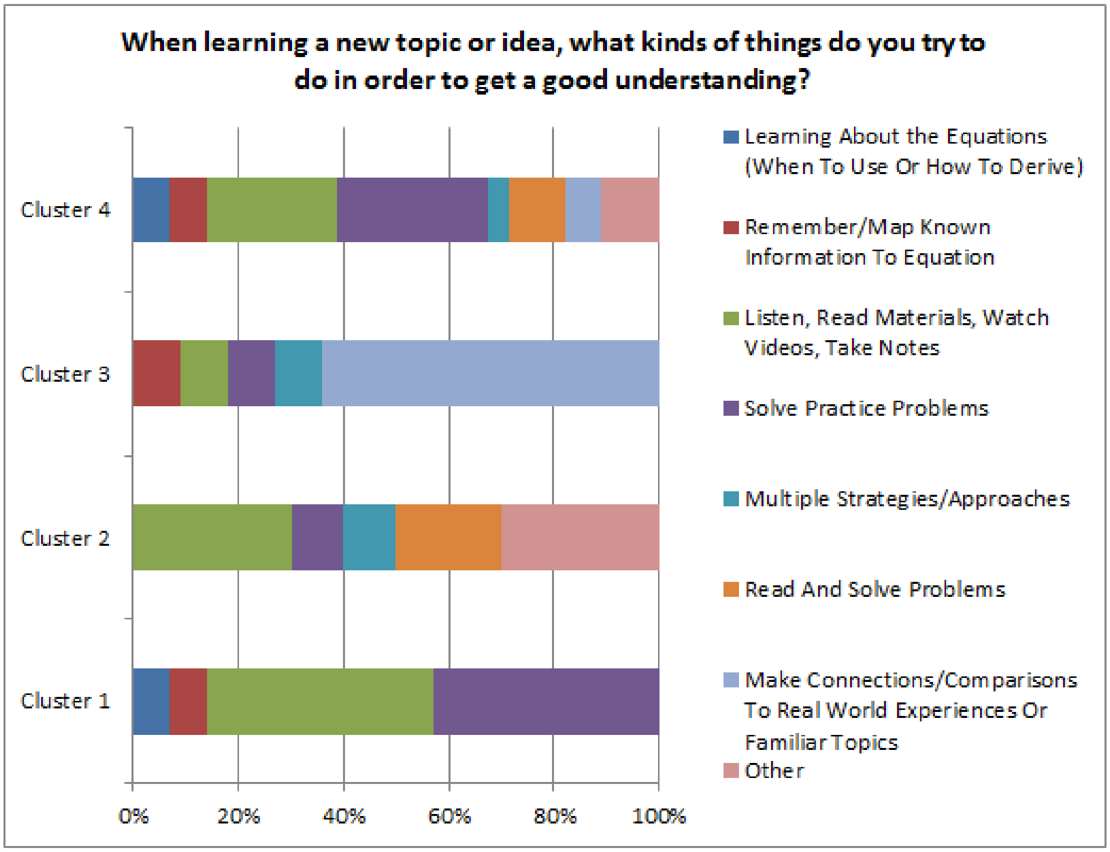

Figure 4.10 Percentage of codes in each cluster for “When learning a new topic or idea, what kinds of things do you try to do in order to get a good understanding?”

Patterns from the Interviews

Table 4.1 indicates the participants in each interview and how their sense-making activities were characterized.

Table 4.1 Student Participants in Interviews

Interview Number	Pseudonym	Cluster
Interview One	Patrick Rebekah	4 2 or 3
Interview Two	Chris	4
Interview Three	Victor	1,2, or 3
Interview Four	Roger	3

For a student, Patrick, whose answers are coded as write out formulas (stuck to unstuck), break into components (new reasoning), solve lots of problems (mastery) and gets correct answer (understanding) very easily fits into cluster 4. Although these codes make it sound like he should be a problem-oriented thinker his answers do not necessarily match those of other problem-oriented students. Only one of his answers does not have a majority of answers in cluster 4 as can be seen in Figures 4.6-4.10. The other answer was completely in cluster 2.

When asked about what he does when he gets stuck on a problem, Patrick said, “I try to first look at the formulas, the different formulas from the chapter or you know does it involve like acceleration or velocity or force or whatever. Then try to write out the formulas and see how if any of these variables relate to one another in the formula.” He focuses on the variables involved in the equation. He answered the question about new reasoning skills with, “Well definitely, try to break it down into every single little bit of information like say you got a vector you are going to want to break it down into x- and y-components like #1 and then you know be more aware of how the forces are acting on each other.” When asked how he gains mastery of a topic Patrick said, “I guess it kind of loops back to practice, practice, practice. You know like if you gave me a homework assignment where I could do unlimited amount of chances to get a problem right, then that would be just fantastic.” Patrick was then asked how does he know when he understands an idea in physics really well. He answered, ”I mean I really, there was at one point where I did a problem and it all made mathematical sense to me but I got the wrong answer you know. I mean maybe I didn't really understand it completely but usually getting the right answer is almost always the case that I absolutely know what they are talking about otherwise it might be an arithmetic error but it's really hard to point out those things.” It is interesting that he talks about times when working a problem did not work before he describes when it did work.

However, for the student, Rebekah, whose answers coded as back track through problem (stuck to unstuck), understands concepts (new reasoning), read book and do problems (mastery), and can work problem straightforwardly (understanding) can easily fit into cluster 2 (Problem-Oriented Sense-Maker) or 3 (Real-World Connector). When asked how to get unstuck from a problem she replied, “When I get stuck I usually try to pinpoint the last understood thing and then sometimes I start over.” This is a very typical answer for the backtrack code. When talking about new reasoning skills Rebekah said, “In high school when I took physics she, my teacher, basically gave us all of the values we needed to solve the problem and we just had to plug them in. We never got the “gist” of the explanation and now I understand why I am putting in those number instead of just plugging in numbers.” She had evolved from a plug-and-chug way of solving problems to being able to understand the underlying concepts involved in the problem. When asked about strategies to master a topic Rebekah answered, “I usually read the book, cause for me it like puts everything into perspective, it goes the long way not just bits and pieces. And then I usually go through all the notes and examples and then I do the practice problems and then I do the practice test.” She is very much into using all the materials supplied to her to gain mastery. When talking about how you know when you understand a topic she responded, “When I can do a problem from the practice test without having to use my notes or (mumble) ask questions.” Another interesting thing she reported was, “The only thing I don't like is when he eliminates steps cause I am one of those people who needs to see all the steps even though I know that you don't necessarily have to do that step but I get lost in between when there is all the eliminating."

Rebekah also participated in a problem solving interview. From that interview I was able to get more information about how she engaged in sense-making with particular problems. This student identified herself as a "math person", and although she had problems using the equations correctly, she definitely fits into Cluster 2 (Problem-Oriented Sense-Maker). This makes her comment about the teacher skipping steps even more interesting since doing multiple calculations in one step is common practice in math classes. She also had trouble with remembering to bring down all the parts of an equation between steps and admitted to having trouble with some basic math notation (fraction bars). In her problem solving interview she talks about how she goes through her notes to help get unstuck, knows she understands a topic when she can answer the problem correctly, and talks through the problem to understand it as new reasoning, all of which are strong indicators of Cluster 2.

Roger was another student who had a clearly defined cluster: Cluster 3 (Real-World User). He reported that when he is stuck on a problem, he asks for help. "Well that's a tough one, our homework is online and some of the, if I am like really truly stuck, some of them have hints to them that I can go through. Some of them don't so there has been a problem with a couple problems where I have been stuck and have had no direction where to go. They don't all have hints and I mean when you are setting up a multi-step calculation and I can't and if I get the answer wrong I can't go back and see what I did wrong, I just know that something wasn't right. So the only way for me to really figure it out is to ask about it or go to the learning center, which I have yet to do but probably should." Roger reported that his new reasoning skills included thinking critically which fell into the "other" code. When asked about it he said, "Most of it is just critical thinking. The more I practice at critical thinking the better I get at it I guess. The more I sit down and actually think about something, sometimes I guess I spend a little more time thinking about something but I guess that is just how I am." For what he does to master a topic he answered that he reads and take notes, this was coded as listen, read materials, watch videos, take notes which is found in all four clusters. He specifically said, "Well I usually read up on everything beforehand. I read whatever part we are working on before we start. And I take notes as I read, I am kind of ridiculous with notes. So usually if I don't understand something it gets reiterated in class and if not I will just ask questions." Roger said he knows he understands a topic when he can solve many problems correctly. When asked about how he knows he understands he said, "Some things I have to read a few times or work a couple different problems but I usually I like to practice a lot, so I will work a few problems a couple different times. I will do it one day and come back maybe two or three days later work it again, see if I understand it." Overall, Roger answered three of the four questions consistent with students in Cluster 3, the Real-World Users. His answer of "thinking critically" as a new reasoning skill fit into Cluster 4.

The student Chris is very similar to Patrick in that 3 of his 4 codes matched the Other-Thinkers cluster. He had getting the correct answer as a response to how do you know when you understand, this fit into Cluster 2.

The student Victor was an interesting case because he did not clearly fit into any of the clusters. If he got stuck on a problem, Victor would backtrack through the problem to get unstuck, this codes to Clusters 3 and 4. He can now draw diagrams to help him solve the problem at hand, which codes to Clusters 1 and 3. Victor gains mastery by reading his notes and solving problems which codes to Clusters 2 and 4. He knows he understands a topic when he can solve multiple problems correctly which codes to Cluster 2. There is no clear distinction which cluster is the correct placement for Victor.

For some students it is an easy process to see which cluster they fit into while others are difficult to place. Not all students will fit into our set categories but most should relate to at least one in some way. In the case of Victor it would make sense for him to fall into the Other Sense-makers category, since cluster four is a sort of catch all group for those who don’t fit anywhere else.

CHAPTER 5

DISCUSSION AND LIMITATIONS

Discussion

One of the interesting things I found was that when asked what it means to “think like a physicist” nineteen percent of students did not have a clear answer. One example of these unclear answers is, “Being able to take large amounts of information that is near impossible to interpret and solving a problem with it.” A favorite of the unclear answers is, “E=mc^2 :).” There were some students with very definitive answers (“Having a good understanding of fundamental laws and using those laws to justify or solve problems that you are given “) but nineteen percent is a surprisingly large portion of the students who are unable to articulate an answer.

Another interesting thing I saw was the number of students who do not try to get help or work in groups. Cooperative learning is a standard practice in upper level courses and it would be interesting to see the point at which students decide working alone is not working for them.

From the research we are able to see that for a population similar to the University of Memphis, there are three major types of sense-making techniques used by the students as described by the clusters. This is important to note since if this is the way students are learning it themselves then it may be useful for it to be taught in this manner. For those students who do not already have these sense-making habits they may learn these helpful ways of thinking and become more successful at physics.

We also see from Rebekah that even though a student identifies themselves as a certain “type” of student (like math) does not necessarily mean they have a strong grasp on the concepts of that type. Rebekah had a lot of trouble getting from one step to the next without losing some of the notation. She also had trouble with the sign of the number when it was being squared. These things are not congruent with what one would believe to be a “math type of person”.

During the cluster analysis we had many students answer the “how do you know when you understand a question” with when “I get the right answer”. But what if they are not supplied with the correct answer, what do they do? How do they know if the answer is right? In the problem solving interview with Rebekah we can see such a case. Rebekah was given the following problem: “You are driving down the highway one night at 20.0 meters per second when a deer steps onto the road 35 meters in front of your car. Your reaction time before stepping on the brake is 0.50 seconds. The maximum deceleration of your car is 10.0 meters per second squared. How much distance is there between you and the deer when you come to a stop?” She starts off very well by drawing a picture of the situation and writing out all the knowns and unknowns. She then does something very interesting and adds that she needs to find the acceleration of the car and the distance it traveled before you saw the deer.

Rebekah works on finding these values for almost four minutes without realizing they are unnecessary. She then pauses and when asked what she is thinking she replies, “I'm thinking I don’t know how to do this problem.” We then talked about the velocity that was given to us and what it meant and she was able to get on the right path. Rebekah then solves how long she travels during the reaction time and gets the wrong answer. Here is her logic when she gets the answer: “So 100 meters is the distance during your reaction time but your deer is here. So you go all this way and then you realize it here but it takes you this long to start the deacceleration. So, you know that, what you are trying to find is the distance you are from the deer. So you have that you went 100 meters. Oh, well that's not right because there is only 35 meters between you and the deer. So, this can't be 100 meters.” She then goes back and discovers an error in her math and gets the correct answer. It is interesting to see how Rebekah used her everyday knowledge to see that the answer she originally arrived at was not acceptable.

Soon after, she gets stuck again. “So we have vi-vf=2ad what I like to do is go ahead and solve it for the d. Apparently I am negative one meters from the deer. Or I went negative one meters here so that is not right. So I can't use that. Or this is really supposed to be squared and I have mixed up my two problems.” Rebekah once again realizes that she has come up with a non-realistic answer and has made a mistake somewhere. She was good at seeing her mistakes and would also use her units to see if she had a realistic answer. It was very intriguing to see Rebekah’s logic played out during the interview using units and orders of magnitude.

Limitations

This research's breadth was highly restricted due to the low number of student participants although it is still applicable to the University of Memphis. The students may not have been willing to participate due to a lack of incentive. Two students were willing to come to interviews but they had already withdrawn from the course. It is hard to draw any overall conclusions because of the limited number of students and the lack of diversity in the demographics of the participants.

This research could be continued over more semesters and possibly provide some sort of incentive for the interviews. This will add to the numbers involved and may allow more insights from further interviews.

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