HOW ARE LEARNING PHYSICS AND STUDENT BELIEFS ABOUT LEARNING PHYSICS CONNECTED? MEASURING EPISTEMOLOGICAL SELF-REFLECTION IN AN INTRODUCTORY COURSE AND INVESTIGATING ITS RELATIONSHIP TO CONCEPTUAL LEARNING

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

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ABSTRACT

As physics teachers, we expect students in our classes to gain an understanding of the true nature of physics knowledge; to see that it is a coherent system of concepts synthesized from careful observations of the real world, rather than a loose collection of facts handed down by experts. These different views about the nature of knowledge and learning are called *epistemological beliefs*. They are not only an important instructional goal in their own right, but they also play an important role in the learning process itself.

Research into students’ epistemological beliefs and how they develop suggests that these beliefs depend on the particular content domain about which students have beliefs and the specific context in which the beliefs are expressed and measured. To explore students’ epistemological beliefs in a variety of conceptual domains in physics, and in a specific and novel context, this Dissertation makes use of Weekly Reports, a class assignment in which students reflect in writing on what they learn each week and how they learn it. The reports were assigned to students enrolled in the introductory physics sequence of the Freshman Engineering Honors program at the Ohio State University, during the 2000-2001 and 2001-2002 school years.

The Weekly Reports of several students from the first year’s course were analyzed for the kinds of epistemological beliefs exhibited therein, called *epistemological self-reflection*, and a coding scheme was developed for categorizing and quantifying this reflection. In a pilot study of twelve students with extremely high or low conceptual
learning gains (as measured by standard conceptual physics instruments), it was found that the “high gainers” tended to describe learning physics concepts in terms of logical reasoning and making personal connections, while the “low gainers” preferred to mention learning from authority figures or simply by observing phenomena without making inferences.

This apparent connection between epistemological self-reflection and conceptual learning in physics was replicated in a larger study, in which the coded reflections in the Weekly Reports of thirty students from the same course were correlated with their conceptual learning gains. Although the total amount of epistemological self-reflection was not found to be related to conceptual gain, the different kinds of epistemological self-reflection found to be important in the pilot study were also significant predictors of gains in this study. Linear regression equations were determined in order to quantify the effects on conceptual gain of specific ways of describing learning.

In an experimental test of this model, the regression equations and the Weekly Report coding scheme developed from the first year’s data were used to predict the conceptual learning gains of thirty students from the second year. The prediction was unsuccessful, possibly because the students in the second year were not given as much feedback on the quality of their reflection as were the first-year students.

The results of these studies show that epistemological beliefs are important factors affecting the conceptual learning of physics students. In addition, getting students to reflect meaningfully on their knowledge and learning is difficult, but it can be done with consistent feedback. More research into the epistemological beliefs of physics students in different contexts and from different populations can help us develop a more complete model of epistemological beliefs, and ultimately improve the conceptual and epistemological knowledge of all students.
Science is a way to teach how something gets to be known, what is not known, to what extent things are known (for nothing is known absolutely), how to handle doubt and uncertainty, what the rules of evidence are, how to think about things so that judgments can be made, how to distinguish truth from fraud, and from show.

Richard P. Feynman, 1963
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CHAPTER 1

INTRODUCTION AND OVERVIEW

1.1 Context of the Research

Experienced teachers are aware that many students complete science courses without learning the basic concepts and skills that teachers intend for them to learn. Consequently, the need for educational reform is widely recognized, and many reforms have been made over the years. In order for reform to achieve lasting success, however, it must be based on a solid foundation of research on student learning. A recent report by the National Research Council points out:

No one would think of getting to the Moon or of wiping out a disease without research. Likewise, one cannot expect reform efforts in education to have significant effects without research-based knowledge to guide them.¹

The need for this research, however, has not been met. Another NRC report stipulates that ... the complex world of education does not rest on a strong research base. In no other field are personal experience and ideology so frequently relied on to make policy choices, and in no other field is the research base so inadequate and little used.²
More than two decades ago, members of the physics community recognized this deficiency and began engaging in systematic research in education. Their field, though still young, has created a modest yet growing research base that continues to provide the foundation for a number of reforms in physics education and has inspired similar research in other science disciplines.³

1.1.1 Research in Physics Education

As a field of study, physics education research (PER) is similar to any applied science in that it involves observation and experimentation, theory construction, and development.⁴ This is elaborated in the following list:

- **Observations** are made of student reasoning and achievement, both informally and in carefully controlled experiments.
- **Theories** or models are constructed that serve to interpret our observations.
- **Development** of instructional strategies is guided by these theories and is followed up with implementation and assessment.

The initial results of this research confirm what was suspected: that there is indeed a gap between what is taught in physics classes and what is learned.⁵

Conceptual understanding and problem solving

Most of the early research in physics education was focused on students’ conceptual understanding in physics, especially in introductory mechanics.³ Researchers discovered, mainly through individual interviews, that students had many common difficulties explaining qualitatively the physical principles they were expected to master, even after instruction. Much of the subsequent work in the field has focused on creating surveys to measure more broadly the existence of these difficulties, identifying their underlying causes, and designing instruction that addresses them more effectively. Even as certain conceptual difficulties are found to be widespread, many innovative instructional
strategies have been shown to make a positive difference in improving conceptual understanding.\textsuperscript{3,6}

In addition to conceptual understanding, students’ problem-solving ability and investigative skills have also been the subject of much research, including work done at Ohio State.\textsuperscript{7} The ability to solve complex, real-world problems and the ability to design and conduct systematic investigations are among the most important skills people use in the workplace, according to several recent studies.\textsuperscript{8} In fact, these studies find them more important than science content knowledge for people in most careers, even engineering.\textsuperscript{9} Researchers have studied what characterizes expert and novice problem solving in physics, the development of problem-solving skills, and effective methods for improving students’ problem-solving abilities.

\textbf{Epistemological beliefs}

Effective problem-solving skills may require other kinds of knowledge called “epistemological beliefs,” the primary area of study of this dissertation. There is growing recognition in research that students’ epistemological beliefs (or “epistemologies”) play an important role in helping them construct knowledge. Epistemological beliefs in physics go beyond physics content knowledge, and consist of attitudes and beliefs \textit{about} knowledge itself, about learning, and about learners. Students with appropriate epistemologies are those who understand the nature of science, how scientific knowledge is constructed, how to monitor and improve their own learning, and how to think scientifically about the physical world. Many believe that improving students’ epistemological beliefs is an important goal in its own right,\textsuperscript{10} others may see it only as a possible means to improve conceptual understanding and problem-solving skills.

Epistemological beliefs have always received attention from education researchers, and interest among both teachers and researchers within the physics community has
increased dramatically in recent years.\textsuperscript{11} We expect students in our courses to gain an understanding of the true nature of physics knowledge; to see that it is a coherent system of concepts synthesized by individual learners from careful observations of the real world, rather than a loose collection of facts handed down by experts. Research has found, however, that this is seldom the case.

As described in Chapter 2, some of the research on students’ epistemological beliefs suggests that they are not general, but instead are dependent on the specific content domain. In other words, a student may believe things about physics knowledge that she doesn’t believe about music knowledge, or even about knowledge in other natural sciences. It is even possible that epistemological beliefs are dependent on even more specific domains; beliefs readily applied in learning about the conservation of momentum, for example, may not get much use in the learning of magnetic induction.

In addition, research suggests that epistemological beliefs depend on the context in which they are measured. Carefully-designed surveys and interview protocols, the methods most commonly used for probing beliefs, may produce different results from observations of a classroom discussion, simply because students may be using different beliefs in these different contexts.

\textbf{1.1.2 Research Presented in this Dissertation}

Since epistemological beliefs may depend on the specific content domain, even within the general domain of “physics,” measurements in a variety of conceptual areas will have a better chance of more accurately reflecting the diversity and consistency of students’ beliefs. Since beliefs might also depend on the particular way in which they are measured, measurements that are more closely tied to the true context of learning than surveys and interviews may get results that are more relevant to instruction.
To address these problems, this study makes use of Weekly Reports, open-ended journals that have been used in a number of different courses. In these reports, students reflect on their learning in a given week, by responding to specific questions. Of special importance to this research are the questions, “What did you learn this week?” and “How did you learn it?” Weekly Reports provide a unique context for research into students' epistemological beliefs about different areas of physics knowledge. The reports have been used for two years in an existing introductory physics course for honors engineering majors at The Ohio State University.

**Epistemological self-reflection**

The written reflections of these students on their learning of physics, as exhibited in their Weekly Reports, is what I have called *epistemological self-reflection*. It includes a few types of epistemological beliefs; namely, beliefs about the content of the student’s physics knowledge, about its structure, about the connection of physics knowledge to the real world, and about how the student learns new knowledge and evaluates it. Epistemological self-reflection is also related to metacognitive skill, that is, the ability to reflect on and articulate one’s thinking. A student’s expectations and attitudes about the physics course also play a role in epistemological self-reflection, since Weekly Reports are a class assignment. Regular written epistemological self-reflection is a new context in which to study epistemological beliefs in a variety of physics content domains.

**The connection with conceptual learning**

It has been suggested that epistemological beliefs affect how concepts are learned, by influencing student thinking about those concepts and by mediating the student’s choice of study strategies. For example, a student who believes that physics consists of disconnected facts and formulas may choose to study primarily by memorizing equations.
Until now, however, this possible connection between epistemology and conceptual learning in physics has not been measured on a broad scale.

Research Questions

The novelty of studying epistemological self-reflection, and its relationship with conceptual learning, are the focus of the four Research Questions of this dissertation:

1) What kinds of epistemological self-reflection do students exhibit in Weekly Reports?
2) Can students’ epistemological development be traced and/or explained throughout the time of a physics course?
3) Does the amount of epistemological self-reflection relate to conceptual learning?
4) Does the kind of epistemological self-reflection relate to conceptual learning?

More detailed motivation for each question is provided in Chapter 2.

The ultimate goal of this dissertation is to develop a universal model for characterizing the epistemological self-reflection seen in Weekly Reports and its relationship to conceptual learning.

1.2 Research Methods

What follows is a brief description of the methods used in this research for measuring epistemological self-reflection, conceptual learning, and the relationship between them. More specific explanations are provided in subsequent chapters.

Students’ epistemological self-reflection was measured by analysis of their written Weekly Reports. Detailed, qualitative descriptions of students’ reports were used to explore in more depth the nature of students’ epistemological self-reflection and to provide a basis for further research in this area. In addition, a coding scheme was developed to characterize and quantify the different types of reflection that were found in the reports. Each report was coded with a number of different codes, each of which
represents a particular way of describing knowledge or learning. Indications of each code (called “code indications”) were counted in each report for each student.

The conceptual understanding of each student was measured with two research-based, multiple-choice, conceptual surveys, one covering kinematics and Newtonian forces and the other elementary electricity and magnetism. Surveys were administered both before and after instruction in the subject of the survey. Conceptual learning was determined by calculating the normalized gain of each student on each of these tests.

To compare kinds of epistemological self-reflection among different students, statistical t-tests were used to test for significant differences in numbers of code indications. Comparisons of kinds of epistemological self-reflection with conceptual learning gains were made with multiple linear regression. This type of mathematical correlation involves several independent variables (in this case, numbers of code indications) and a single dependent variable (normalized gain on one of the conceptual surveys).

1.3 Overview of the Dissertation

The theoretical considerations that underlie this dissertation are presented in Chapter 2, including a review of the relevant research literature, the place of this dissertation within the body of research, and the specific motivation for each research question. Chapter 3 presents a study of the kinds of epistemological self-reflection students exhibit in Weekly Reports. It describes the introductory physics course in which these data were collected, the development of the coding scheme for Weekly Reports, the coding scheme itself, and the domain-dependence of students’ self-reflection. Chapter 4 describes an exploratory study that compares the epistemological self-reflection of 6 students with very high conceptual learning gains with that of 6 students with very low
gains. It includes detailed descriptions of the reports of several students. Chapter 4 also documents the extent to which the development of a students’ epistemological beliefs can be measured over the course of one or two quarters in the context of their reports. Chapter 5 describes a study that statistically compares the self-reflection of 30 students with their conceptual gains and creates an algorithm for predicting conceptual gains from self-reflection code indications. This algorithm, along with the coding scheme described in Chapter 4, constitute an initial model for epistemological self-reflection and its relationship to conceptual learning. Chapter 6 details an experimental test of this model in which the model is applied to data from 30 students in a different class; it includes a measure of the algorithm’s predictive power or lack thereof. Chapter 7 includes a summary of these studies and a discussion of the implications they have for instruction and for future research.
ENDNOTES FOR CHAPTER 1


9 This is reflected in the recently revised standards of the Accreditation Board for Engineering and Technology (ABET) for engineering programs seeking accreditation; these standards are online at http://www.abet.org/eac/2000.htm.

10 Indeed, many instructors include epistemological development as an implicit goal of any physics course; see J. M. Saul, Beyond Problem Solving: Evaluating Introductory Physics

11 For example, there were 6 talks related to epistemological issues given at the 2001 Winter Meeting of the American Association of Physics Teachers, 8 at the 2001 Summer Meeting, and 17 at the 2002 Winter Meeting; see AAPT Announcer 30(4) (2000); AAPT Announcer 31(2) (2001); AAPT Announcer 31(4) (2001); note that these figures do not include talks given at the Physics Education Research Conference that followed the Summer Meeting.

CHAPTER 2

THEORETICAL CONSIDERATIONS

2.1 Review of the Literature

As this dissertation presents studies that compare students’ epistemological beliefs with their conceptual learning gains in elementary mechanics, electricity, and magnetism, this section begins with a brief overview of the research on students’ conceptual understanding in those areas, including the research that led to the development of the conceptual surveys used in this dissertation. It continues with a more detailed summary of the relevant research on students’ epistemological beliefs, the primary focus of the present work, and the relationship between epistemology and conceptual understanding.

2.1.1 Conceptual understanding in introductory physics

Mechanics

About twenty years ago, physicists began the systematic study of college students’ understanding of physics concepts by exploring student difficulties in introductory mechanics, the first and only physics course for many students. They found that students’ conceptions of the physical world were much different from those of experts, even after extended instruction in physics.¹
The trouble, it was discovered, lay primarily in the fact that students don’t arrive in their first physics classes as blank slates. They have prior knowledge and beliefs about the physical world, gleaned from years of personal experience, that affects how they learn (or don’t learn) the principles of physics they are taught. Many of these beliefs, when expressed in a classroom setting, do not appear to be consistent with those of physicists. Some, it turns out, appear to be very stable in most classroom contexts, and persist there despite the best efforts of teachers to eliminate them.2-5 These stable beliefs go by many names in the research literature, such as preconceptions, misconceptions, alternative conceptions, naïve frameworks, and common-sense beliefs.6,7

For an example, consider the work of Trowbridge and McDermott on student understanding of position, velocity, and acceleration in one dimension.8 They conducted individual interviews with 300 students from a number of different university physics courses. In the interviews, students watched as small steel balls were rolled along wooden tracks, some level and some inclined. Students were then asked questions about their observations. A significant number of students confused position with velocity, or velocity with acceleration. In fact, in every case in which position was confused with velocity, students used a position criterion to determine a relative velocity. For example, upon being asked at what point two balls in a particular demonstration had the same speed, these students would explain their response with something like “That’s the place where the two balls are side-by-side, so for that to happen they have to have the same speed.”

Conceptual difficulties have been found as well in many other areas of introductory mechanics, including two-dimensional kinematics, gravitational force, Newton’s Laws of Motion, momentum, energy, rotational motion, and relativity.9 Fortunately, students show many of the same difficulties, making it much easier to measure them and to design instruction that takes them into account. However, although
many students show the same difficulties over and over again, the belief system (or “model”) that underlies them often is not applied consistently. In other words, many individual students seem to have some ideas that are consistent with Newtonian mechanics and some that are decidedly “non-Newtonian.”

This inconsistency implies that students have an unstructured, incoherent knowledge system that is applied very differently in diverse circumstances. This lack of structure has been documented by Minstrell, who identified many of the different facets of students’ knowledge. diSessa has described students’ inconsistency as evidence for his theory that people have a number of small pieces of intuition, called phenomenological primitives or “p-prims,” that they use to explain events. These p-prims are strongly connected to real world experiences, and are usually applied subconsciously. They are not “correct” or “incorrect,” in a scientific sense, but can be applied in unscientific ways. For example, the “force determines direction” p-prim is derived from years of experience in which an object will move in the direction we push it most of the time. When considering pushing an object initially at rest, physicists will usually use this p-prim (subconsciously) rather than construct a force diagram and apply Newton’s second law. Although students apply the “force determines direction” p-prim correctly in this situation, they often also apply it (inappropriately) in situations in which an object is moving in a direction other than that of the applied force. According to diSessa’s theory, then, the apparent inconsistency of students’ beliefs is explained by the fact that many students haven’t yet learned which of their physical intuitions to apply in which contexts.

Electricity and magnetism

There has been significantly less research on students’ understanding of electricity and magnetism concepts. Most of it has explored the conceptual areas of dc circuits and electric and magnetic fields. Just as in elementary mechanics, numerous common
misconceptions have been found in electricity and magnetism. For example, Viennot and Rainson found that many students have difficulties understanding the causes and effects of electric fields.\textsuperscript{13} Also, Guruswamy \textit{et al.} discovered that a considerable number of physics students in many different age groups could not accurately predict the transfer of electric charge from one conductor to another.\textsuperscript{14} In another interesting study, Maloney found that many students believe that electric charges will react to magnetic poles, even after instruction on these topics.\textsuperscript{15}

**Improving instruction**

Ever since physicists began to study student difficulties in physics, they have also worked on the problem of how to prevent or eliminate them. A number of innovative instructional approaches have been developed, with different amounts of success. Most of them make use of some of the well-established principles developed over the last century by researchers in cognitive and educational psychology. Perhaps the most important of these is that of \textit{constructivism}, the idea that students build their knowledge by processing the information they receive, making connections between what they already know and what they learn. For this reason, most research-based instructional innovations have entailed some form of “interactive engagement” strategy, in which students’ minds are more reliably engaged than in more traditional passive-student approaches.

Most of these innovations have retained the lecture format, but modified it to make it more interactive.\textsuperscript{16} Many have replaced a portion of lecture or traditional recitations with specially structured cooperative group work\textsuperscript{17} or tutorials.\textsuperscript{18} Others have changed the goals of instructional laboratories from traditional verification to exploration, hypothesis testing, or design.\textsuperscript{19} A few instructional approaches have eliminated lectures altogether and consist entirely of cooperative group lab work.\textsuperscript{20} Many of these, and other, innovations
were reviewed by Van Heuvelen. The research-based instructional strategies used in the physics course studied in this dissertation are described in Chapter 3.

Development of the Force Concept Inventory

Once these new instructional strategies were developed and implemented, they needed to be evaluated and compared with traditional instruction. With this need in mind, Halloun and Hestenes set out to create a multiple-choice diagnostic instrument that was easy to analyze and that reliably showed the effectiveness of a particular instructional approach. Using the existing results of research in mechanics concepts, they first designed the Mechanics Diagnostic Test (MDT). It was deliberately written in everyday, nontechnical language, so that students could readily understand it without formal physics knowledge. In this way, it could be given both after and before instruction, in order to measure conceptual change.

Early versions of the MDT included free-response questions, and were later turned into multiple-choice items in which the distracters (incorrect answer choices) reflected common misconceptions. After analyzing the results from administering the MDT to over 1000 students, Hestenes and others created the Force Concept Inventory (FCI), which is used in this dissertation. The FCI is similar to the MDT, but more precisely identifies student difficulties with particular concepts (such as Newton’s First Law of Motion) and the misconceptions that underlie those difficulties. A list of the misconceptions suggested by a student’s choice of a particular answer is provided in Table 2.1.

The FCI is a very specific diagnostic, covering concepts related to Newton’s Laws of Motion and a few from basic kinematics, but no others. Still, it is perhaps the instrument most used by physics teachers to evaluate the effectiveness of their instruction in introductory mechanics.
<table>
<thead>
<tr>
<th>Misconception</th>
<th>Inventory Item</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>0. Kinematics</strong></td>
<td></td>
</tr>
<tr>
<td>K1. Position-velocity undiscriminated</td>
<td>20B,C,D</td>
</tr>
<tr>
<td>K2. velocity-acceleration undiscriminated</td>
<td>20A;21B,C</td>
</tr>
<tr>
<td>K3. nonvectorial velocity composition</td>
<td>7C</td>
</tr>
<tr>
<td><strong>1. Impetus</strong></td>
<td></td>
</tr>
<tr>
<td>I1. impetus supplied by 'hit'</td>
<td>9B,C;22B,C,E;29D</td>
</tr>
<tr>
<td>I2. loss/recovery of original impetus</td>
<td>4D;6CE;24A,26A,D,E</td>
</tr>
<tr>
<td>I3. impetus dissipation</td>
<td>5A,B,C;8C;16C,D;23E;27C,E;29B</td>
</tr>
<tr>
<td>I4. gradual/delayed impetus build-up</td>
<td>6D;8B,D;24D;29E</td>
</tr>
<tr>
<td>I5. circular impetus</td>
<td>4A,D;10A</td>
</tr>
<tr>
<td><strong>2. Active Force</strong></td>
<td></td>
</tr>
<tr>
<td>AF1. only active agents exert forces</td>
<td>11B;12B;13D;14D;15A,B;18D;22A</td>
</tr>
<tr>
<td>AF2. motion implies active force</td>
<td>29A</td>
</tr>
<tr>
<td>AF3. no motion implies no force</td>
<td>12E</td>
</tr>
<tr>
<td>AF4. velocity proportional to applied force</td>
<td>25A,28A</td>
</tr>
<tr>
<td>AF5. acceleration implies increasing force</td>
<td>17B</td>
</tr>
<tr>
<td>AF6. force causes acceleration to terminal velocity</td>
<td>17A;25D</td>
</tr>
<tr>
<td>AF7. active force wears out</td>
<td>25C,E</td>
</tr>
<tr>
<td><strong>3. Action/Reaction Pairs</strong></td>
<td></td>
</tr>
<tr>
<td>AR1. greater mass implies greater force</td>
<td>2A,D;11D;13B;14B</td>
</tr>
<tr>
<td>AR2. most active agent produces greatest force</td>
<td>13C;11D;14C</td>
</tr>
<tr>
<td><strong>4. Concatenation of Influences</strong></td>
<td></td>
</tr>
<tr>
<td>CI1 largest force determines motion</td>
<td>18A,E;19A</td>
</tr>
<tr>
<td>CI2. force compromise determines motion</td>
<td>4C;10D;16A;19C,D;23C;24C</td>
</tr>
<tr>
<td>CI3 last force to act determines motion</td>
<td>6A;7B;24B;26C</td>
</tr>
<tr>
<td><strong>5. Other Influences on Motion</strong></td>
<td></td>
</tr>
<tr>
<td>CF. Centrifugal force</td>
<td>4C,D,E;10C,D,E</td>
</tr>
<tr>
<td>Ob. Obstacles exert no force</td>
<td>2C;9A,B;12A;13E;14E</td>
</tr>
<tr>
<td><strong>Resistance</strong></td>
<td></td>
</tr>
<tr>
<td>R1. mass makes things stop</td>
<td>29A,B;23A,B</td>
</tr>
<tr>
<td>R2. motion when force overcomes resistance</td>
<td>28B,D</td>
</tr>
<tr>
<td><strong>Gravity</strong></td>
<td></td>
</tr>
<tr>
<td>G1. air pressure-assisted gravity</td>
<td>9A;12C;17E;18E</td>
</tr>
<tr>
<td>G2. gravity intrinsic to mass</td>
<td>5E;9E;17D</td>
</tr>
<tr>
<td>G3. heavier objects fall faster</td>
<td>1A;3B,D</td>
</tr>
<tr>
<td>G4. gravity increases as objects fall</td>
<td>5B;17B</td>
</tr>
<tr>
<td>G5. gravity acts after impetus wears down</td>
<td>5B;16D;23E</td>
</tr>
</tbody>
</table>

Table 2.1: A list of misconceptions probed by the Force Concept Inventory. Presence of the misconception is suggested by selection of the corresponding inventory item.
Using the FCI, Richard Hake investigated the effectiveness of 62 high school and college physics classes (with a total of more than 6000 students). Fourteen of these classes were taught using traditional lecture methods; the other 48 used some form of interactive engagement, as defined by the instructors. In each class, the FCI was given as a pretest (before instruction) and as a posttest, and class averages calculated. Hake found that although the gain (posttest score – pretest score) was strongly correlated with the pretest score for each class (a result he did not find surprising), the normalized gain was not correlated with pretest score at all. The normalized gain \( g \) is defined as the class gain divided by the class’s maximum possible gain, given its average pretest score. In other words,

\[
< g > = \frac{< post > - < pre >}{100\% - < pre >},
\]

where \(<pre>\) and \(<post>\) are the class-averaged pretest and posttest scores, respectively. Normalized gain, then, can be thought of as the fraction of the maximum possible gain that a class achieves.

Hake’s result was dramatic. While the 14 traditional classes had an average normalized gain of 0.23 (±0.04, standard deviation), the interactive engagement classes did much better, achieving a normalized gain of 0.48 (±0.14). Hake went on to define an “interactive engagement zone,” a range of FCI normalized gains in which most of these types of classes were expected to lie: between 0.36 and 0.68. A number of studies of various interactive engagement methods before and since Hake’s investigation are consistent with his findings.

**Development of the Conceptual Survey of Electricity and Magnetism**

Although there has been much less research on student conceptual understanding in E & M than in mechanics, enough was known for researchers to develop the
Conceptual Survey of Electricity and Magnetism (CSEM), the other conceptual instrument used in this dissertation. Unlike the FCI, the CSEM was not designed to diagnose specific misconceptions. Instead, it was intended to be a survey of student knowledge in a broad range of topics. A list of these topics, and the CSEM items that address them, is shown in Table 2.2.

<table>
<thead>
<tr>
<th>Conceptual area</th>
<th>Item numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Charge distribution on conductors/insulators</td>
<td>1, 2, 13</td>
</tr>
<tr>
<td>II. Coulomb’s force law</td>
<td>3, 4, 5</td>
</tr>
<tr>
<td>III. Electric force and field superposition</td>
<td>6, 8, 9</td>
</tr>
<tr>
<td>IV. Force caused by an electric field</td>
<td>10, 11, 12, 15, 19, 20</td>
</tr>
<tr>
<td>V. Work, electric potential, field, and force</td>
<td>11, 16, 17, 18, 19, 20</td>
</tr>
<tr>
<td>VI. Induced charge and electric field</td>
<td>13, 14</td>
</tr>
<tr>
<td>VII. Magnetic force</td>
<td>21, 22, 25, 27, 31</td>
</tr>
<tr>
<td>VIII. Magnetic field caused by a current</td>
<td>23, 24, 26, 28</td>
</tr>
<tr>
<td>IX. Magnetic field superposition</td>
<td>23, 28</td>
</tr>
<tr>
<td>X. Faraday’s law</td>
<td>29, 30, 31, 32</td>
</tr>
<tr>
<td>XI. Newton’s third law</td>
<td>4, 5, 7, 24</td>
</tr>
</tbody>
</table>

Table 2.2: Conceptual areas and question numbers that address each conceptual area for the CSEM.

2.1.2 Epistemological beliefs

Researchers have characterized personal epistemological beliefs in a number of different ways. Most include beliefs about how knowledge is constructed and evaluated
and how knowing occurs. Most have chosen to think of epistemology as a sequence of developmental stages or as a few orthogonal dimensions. Research suggests that students’ personal epistemological beliefs depend on the particular content domain in question, and that they depend on the specific context in which they are measured. Related to epistemology are students’ expectations about a particular physics course and their metacognitive abilities. Epistemological beliefs are an important instructional goal in their own right, but may also be connected to conceptual learning in a number of ways.

The nature of epistemological beliefs

Beginning with Perry, most studies of epistemological beliefs have suggested models consisting of unidimensional, developmental stages. In these models students are thought to move through these stages in some fashion (not necessarily in an invariant sequence). The stages are similar in each of these models. Perry labels them this way:

1) **Dualism** - knowledge is certain and comes directly from authority.
2) **Multiplism** - knowledge is subjective and never certain or absolute; every view has equal value.
3) **Relativism** - knowledge can be certain to different degrees and must be judged in each context.
4) **Commitment within relativism** - some knowledge can be accepted and applied.

Perry found dozens of college students in each of the first three stages, and only very few in the last.

Schommer has proposed instead that epistemological beliefs are best measured in several orthogonal dimensions. In each dimension, students’ beliefs lie somewhere between two extremes, one favorable and one unfavorable (in Schommer’s judgment). Schommer labelled each of the four dimensions she proposed in terms of its unfavorable extreme:
• **Certain Knowledge** - knowledge does not evolve but is fixed and certain.

• **Simple Knowledge** - knowledge consists of disconnected pieces of information.

• **Quick Learning** - learning happens instantly or not at all.

• **Fixed Ability** - one's level of intelligence cannot change.

Schommer describes most of the college students in her studies as having these beliefs. Only a few students take the opposite positions on any of these four dimensions. The Epistemological Beliefs Questionnaire created by Schommer\(^2^7\) has been used by a number of researchers to measure beliefs along these dimensions, with varying degrees of success.\(^2^3\)

Hofer and Pintrich use *personal theories* as an alternative to orthogonal dimensions and stage models to describe a learner’s system of epistemological beliefs.\(^2^6\) These learner-held theories are inherently multidimensional, but the dimensions are integrated into a coherent system. As dimensions of personal theories, Hofer and Pintrich have taken Schommer's **Certain Knowledge** and **Simple Knowledge**,\(^2^7\) and added **Source of Knowledge** and **Justification for Knowing**, based on their own research and that of others.\(^2^6\) The extreme positions in the **Source of Knowledge** dimension are the belief that knowledge comes from external authority and the belief that knowledge is constructed independently by the learner. **Justification for Knowing** refers to the degree to which the learner seeks to evaluate proposed arguments, observed evidence, or supposed authorities when trying to justify knowledge. **Source** and **Justification** both relate to the three warrants for the viability of knowledge identified by Ritchie *et al.* (1997): authority, coherence, and empirical testing. Hofer points out that a personal theories model allows for differences in students' beliefs about knowledge in different disciplines.\(^2^3\)
Domain-dependence of epistemological beliefs

Most studies have assumed that epistemological beliefs are the same across different content domains. However, it is likely that beliefs can vary widely in different domains. Here, domain refers to the subject of the belief: a particular discipline (such as physics), topics within a discipline (such as electricity, thermodynamics, or quantum mechanics), particular concepts within a topic (such as Newton's 3rd Law, electromagnetic induction, or energy density), or particular tasks performed as part of a discipline (such as solving written problems, designing experiments, or constructing explanations).

For example, it seems like common sense that what makes one a good historian is not necessarily what makes one a good scientist. A few formal studies have provided evidence for this intuition. One study found differences in beliefs about learning in math and social studies among middle-school students. Another discovered that students had different epistemological beliefs about psychology and science. Research conducted on students’ views of different topics within a single discipline found that students in a college astronomy course understood the relationship between evidence and theory in the context of evolution or the Big Bang, but not when considering the theory of gravity.

Citing these studies and others, Hofer and Pintrich call for the need for more domain-specific research in epistemology. In their review of research on epistemological beliefs, they suggest that some elements of epistemological beliefs may be domain-specific while others may be domain-general. They also point out that academic disciplines do in fact have different epistemological assumptions, a fact verified by research. So far, there has been very little research on beliefs in specific disciplines, or on specific content within disciplines. This dissertation aims to meet part of this need; see section 2.2.
Epistemological beliefs in science

A few studies have focused on students’ beliefs about scientific knowledge. These studies show that many students have a poor understanding of various aspects of the nature of science, for example, that it is empirically based. Many high school students consider science as a collection of facts and have trouble differentiating between observational evidence and explanations of this evidence. Their views of the role of scientific models are contrary to the views of scientists, and after years of formal schooling they lack an understanding of the main features that distinguish science from other mental enterprises. Edmondson and Novak summarize some of this research:

College students’ conceptions of the nature of scientific knowledge indicate their need for a better understanding of the way in which “real scientists” generate and justify their claims. Although their understanding of the methodology required for “doing science” is adequate, most students seem to have no understanding of the ways in which scientists’ thinking evolves and is translated into formal inquiry. Nor do they understand the validity or permanence of the knowledge claims that are generated, or the ways in which assertions may be established.

Epistemological beliefs in physics

Thus far only a few researchers have explored student epistemologies in the domain of introductory physics. One of the most extensive and relevant studies is the dissertation of David Hammer. Hammer individually interviewed six students several times over the course of their semester-long, calculus-based introductory physics class for engineering majors at the University of California. All of them had taken physics in high school, and had achieved scores of at least 700 on the math portion of the SAT. Each hour-long interview consisted of open and semi-guided discussion about the class, physics problem solving, and direct questioning. While solving problems in the interviews, the students were asked to speak their thoughts aloud as they worked on a solution.
In the course of analyzing the interview transcripts, Hammer was able to characterize some aspects of the students’ epistemological beliefs. He found that each student’s beliefs were largely consistent throughout the semester. As evidence for these beliefs, he took the fact that they were used by students in understanding the course material and in solving problems, and the fact that they appeared across many different topics in the course. Hammer created a framework to classify these beliefs, proposing three interrelated dimensions for them; namely, beliefs about the structure of physics knowledge, about the content of physics knowledge, and about learning physics. These dimensions are described in Table 2.3. Students with beliefs close to either extreme on each dimension are classified as Type A or Type B.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Type A</th>
<th>Type B</th>
</tr>
</thead>
</table>
| Beliefs about structure | **Coherence**  
Physics can be considered as a connected, consistent framework | **Pieces**  
Physics is made up of separate, unrelated facts or concepts |
| Beliefs about content  | **Concepts**  
Physics consists primarily of concepts, sometimes represented by symbols | **Formulas**  
Physics consists of formulas, focus is on memorizing them |
| Beliefs about learning | **Independence**  
Self-motivated, student questions material until it makes sense to them | **By authority**  
Student takes what is given by instructor or text without evaluation |

Table 2.3: The three dimensions of Hammer’s framework for characterizing students’ epistemological beliefs in introductory physics.\(^{41}\)
With regard to their beliefs about structure, Type A students see the coherence of physics knowledge. They try to understand the derivations of formulas and the connections between different concepts. Type B students, on the other hand, see physics as consisting of pieces such as facts, formulas, or concepts. These pieces are unrelated and must simply be remembered. A problem can’t be solved unless one knows the “right” equation to use. While Type A students often check for consistency in their work, Type B students are unconcerned about apparent inconsistencies. This “coherence vs. pieces” dimension is similar to Schommer’s Simple Knowledge.27

The second of Hammer’s dimensions, about the content of physics knowledge, is related to the first. Type A students focus on the conceptual nature of physics learning, and believe that concepts underlie each equation. Type B students either don’t acknowledge the concepts behind the formulas, or don’t think they’re important for them to know. For them, the formulas are the most important feature in physics.

Learning physics is something that Type A students feel they can only accomplish themselves, by making sense of the material that they encounter and constantly evaluating it (independence). In contrast, Type B students tend to accept the information that is given to them by authority (the instructor or the textbook), neither doubting its correctness nor caring about its justification. This dimension is related to Hofer and Pintrich’s Source of Knowledge and Justification for Knowing.26 Also, the by authority extreme is reminiscent of the first stage in the various stage models of epistemological beliefs (such as Perry’s Dualism).24

Using this framework, Hammer classified two students as Type A and four students as Type B, for all of the dimensions. The Type B students, he found, were more “casual” about making and breaking connections between different pieces of their knowledge, decided quickly whether or not they understood new material, and were
unwilling to spend very long working on a problem for which they did not immediately
know the solution. Type A students, on the other hand, approached building their
understanding with great care, were more reflective and questioning of new knowledge,
and described the problems they could not initially solve as the most interesting.

In their study of high school physics students, Roth and Roychoudhury\textsuperscript{45} found
that student beliefs were not as consistent as in Hammer’s study. They used written
essays, short-answer responses to statements, and a “preferred classroom environment”
inventory to determine the epistemological beliefs of 42 students. In addition, eleven of
these students were interviewed individually. They found that essentially \textit{Dualist beliefs}\textsuperscript{24}
were quite common, even in a particularly constructivist classroom. What’s more, many
students responded in ways consistent with \textit{Dualist beliefs} \textit{and} with more sophisticated
beliefs (such as those espoused by Hammer’s Type A students) on the different types of
measures. Roth and Roychoudhury’s survey and interview questions referred only to
“science” and “physics,” and did not address specific topics within physics.

In an effort to create a standard measure of students’ epistemological beliefs and
expectations about physics classes, researchers at the University of Maryland developed
the Maryland Physics Expectations survey (MPEX), a multiple-choice instrument
designed for introductory physics classes.\textsuperscript{44} Most of the 34 items on the MPEX are in one
of six “clusters” of items. Three of these are directly from Hammer’s framework, and in
each case refer to the favorable extreme: \textit{coherence}, \textit{concepts}, and \textit{independence}.\textsuperscript{41} The
other three clusters are \textit{math link} (on the role of mathematical formalism in learning
physics), \textit{effort} (on what kind of work is necessary for learning physics), and \textit{reality link}
(on the connection between physics and the world outside the classroom). Results of
using the MPEX in a wide variety of physics classes suggest that most students, unlike
physics experts, maintain beliefs that knowledge consists of disconnected facts and
formulas, handed down by authority, that are unrelated to their everyday experiences. These beliefs persist (and usually get worse) during the course of physics instruction.

**Context-dependence of epistemological beliefs**

Not only do beliefs appear to depend on the specific content domain, but they may also depend on the context in which they are applied and measured. The importance of context to any kind of educational research was described by Finkelstein in this way: “Context is central to student learning, not as an analytically separate factor, not as the backdrop to student learning, but as an integral part of the learning process.” It makes a certain amount of intuitive sense that epistemological beliefs might depend on context, as Hammer and Elby have pointed out. One would not expect that a person’s beliefs about the certainty of knowledge, for example, would remain the same across the contexts of a philosophical discussion, a scientific debate, or an everyday exchange of information, even if the topic were held fixed. Likewise, a student who struggles to understand the derivation of a particular equation while studying for a test might simply accept the same equation as given when solving a textbook homework problem.

Again, there is evidence in the research that epistemological beliefs depend on context, particularly the context of measurement. Hofer and Pintrich refer to a number of inconsistencies in students’ beliefs among different assessments (such as different kinds of interviews and surveys). As described above, Roth and Roychoudhury’s subjects showed little consistency across the different measurement methods, none of which was closely tied to the classroom context. Hammer’s extensive study, on the other hand, showed a great deal of consistency in student beliefs; he used a single method, interviews that closely matched the activities of the course (see “Epistemological beliefs in physics,” above).
Hammer and Elby point to the fact that most research has not paid attention to context.\textsuperscript{47} In order to reliably characterize students’ beliefs and their effect on learning, they argue, research must be sensitive to the context of student’s expressions of those beliefs. Epistemological aspects of learning in a science class, then, would best be studied in a science class, with students engaged in authentic class activities. Interviews and surveys are not normal learning activities for students in most classes (and are usually administered outside of class altogether), and so would not be expected to measure the kinds of beliefs students use in a class.\textsuperscript{48} Hofer and Pintrich, Hammer and Elby, and others call for research to be more closely tied to the classroom context. One aim of this dissertation is to fill this need for epistemology research in a particular context, that of regular self-reporting of learning (see section 2.2).

2.1.3 The relationship between epistemological beliefs and conceptual learning

It is important for citizens to develop appropriate beliefs about the nature of scientific knowledge and what it means to learn science, because these beliefs help people understand the science that is ubiquitous in our increasingly technological society. There is also reason to believe that epistemological beliefs relate to one’s ability to learn science concepts.

The first kind of evidence that suggests a connection between epistemology and conceptual learning is from studies that correlate beliefs with academic performance. One of Schommer’s text comprehension studies found that students who believed in \textit{Certain Knowledge} tended to draw conclusions that were inappropriately absolute and thus earned lower test scores.\textsuperscript{27} In another study, Schommer determined that students’ proclivity to believe in \textit{Simple Knowledge} was negatively correlated with their performance at comprehending a statistical passage.\textsuperscript{28} What’s more, each of Hammer’s Type A students
earned an A in their physics course, while none of the Type B students did as well. In fact, the Type B students showed many more difficulties with physics concepts in their interviews than did the Type A students.

Epistemological beliefs have also been linked in a general way to the learning of science. In particular, students who believe that science consists of isolated principles (c.f., Schommer’s Simple Knowledge and Hammer’s coherence vs. pieces) tend not to be able to integrate what they are presented in science class into their existing knowledge structure. Only one other study has measured the relationship between epistemology and conceptual learning in science; it indicated that students with inappropriate beliefs were less successful at replacing their misconceptions with scientific ideas and at reasoning on applied tasks.

One way in which epistemological beliefs may influence conceptual learning is by mediating students’ choice of study strategies. It makes sense that a student’s beliefs would affect her learning behavior; someone who believes that knowledge consists of disconnected facts and formulas, for example, might study for a test by memorizing equations and problem solution algorithms. In fact, it has been shown that a belief in the certainty of scientific knowledge leads students toward rote learning strategies. Students’ beliefs about knowledge also affect their learning goals and motivation, which in turn affect their selection of study strategies. Epistemology may also affect the ways that students evaluate their learning.

In addition, a few studies have shown that conceptual learning in science is often improved by the conscious use of analogies in the learning process. Making analogies may be akin to making connections between otherwise unrelated concepts, an important epistemological skill.
2.2. Contributions of this Dissertation to the Field

2.2.1. Epistemological beliefs in specific domains and contexts (Research Question 1)

The most important contribution of this dissertation is that it responds to the need for research in epistemological beliefs that attends to the specific context of the beliefs and to the particular content domains that are the subjects of the beliefs. Very few prior studies have explored students’ beliefs about physics knowledge, and none have done so in the context of students’ written reflections on how they learn. By using Weekly Reports to measure students’ beliefs, this study aims to fill this crucial gap in our understanding of how people learn.

Of the few studies that describe students’ epistemological beliefs in physics, only Hammer’s focused on students’ beliefs about particular physics problems and principles as the students encountered them each week. So, too, do the Weekly Reports; in answering the open-ended questions, "What did you learn?" and "How did you learn it?", students are encouraged to address specifically their experience in the classroom and the physics ideas they learned that week. This research therefore doubles the number of studies that explore epistemology in specific physics domains.

What is especially novel about using Weekly Reports is the unique context of measurement that they represent. Unlike multiple-choice surveys, they allow students to respond freely in their own words, more accurately reflecting their beliefs. Unlike individual interviews, reports provide a context for reflection that is free of a potentially-intimidating interviewer. They also avoid problems with interpreting students’ body language and tone of voice. Also, while the context of Weekly Reports is not much closer to the regular classroom environment than that of interviews, they at least are an integral
part of the course's instructional agenda. Consequently, they have the advantage of being automatically generated from students’ work in the course.

These considerations lead directly to the first Research Question:
1) What kinds of epistemological self-reflection do students exhibit in Weekly Reports?

By providing an alternative perspective on students’ beliefs, reports may serve to replicate and verify the findings of Hammer’s interviews. Or, if they provide different information than interviews, then we can begin to map out more clearly the context-dependence of epistemological beliefs. This question is addressed in Chapter 3.

2.2.2. Development of epistemological beliefs (Research Question 2)

If appropriate epistemological beliefs are important for students to develop, either because they are important in their own right or because they may facilitate the learning process, then research must also explore the details of how they develop. Studies using stage models (such as Perry’s) have traced students’ epistemological level through a period of several years, often finding improvements. The only large improvements in beliefs as measured by the MPEX (see above) were seen in a year-long high school physics course that had a special emphasis on epistemological development.

It’s not clear that a significant change in students’ beliefs can occur over the course of one or two quarters, even in a class that emphasizes the investigative character of science (see Chapter 3 for a description of the course). If their beliefs do in fact change, can this change be seen in the context of their reports? This is essentially the second Research Question:

2) Can students’ epistemological development be traced and/or explained throughout the time of a physics course?

A measurable change would suggest that one or more aspects of the course are causing the change. More research would be required to discover which one(s). Failure to
see a change would not necessarily imply that a change didn’t happen, only that one couldn’t be seen in the context of these Weekly Reports, and that different measurement methods would be required to observe epistemological development. This question is addressed in Chapter 4.

2.2.3. The relationship between epistemological self-reflection and conceptual understanding (Research Questions 3 and 4)

A connection between epistemological beliefs and a student’s ability to learn science concepts would have substantial implications for instruction. If students can learn more effectively by having a particular epistemological outlook, then teachers and school administrators will need to consider epistemological factors when designing and evaluating elements of instruction such as curriculum, pedagogy, and tools for assessment.

Existing studies on the connection between beliefs and conceptual learning are very few, and are different from the research in this dissertation in many ways. Most of them involved pre-college students rather than university students. They used epistemological measures (mostly surveys) that are very general and not tied to the classroom context. They focused on beliefs about science in general, rather than on physics or on specific physics concepts. This dissertation uses measures (of epistemological beliefs and of conceptual learning) that are specifically attuned to the content of a college physics course.

In this special context, then, it is not yet known to what extent students’ reflection on their learning may be related to their conceptual learning abilities. This leads to the last two Research Questions, about the epistemological self-reflection seen in students’ Weekly Reports. The ability of students to reflect on their learning at all is the important factor in Question 3. When given the opportunity, how much do they reflect?:

3) Does the amount of epistemological self-reflection relate to conceptual learning?
Question 4 deals with what they write when they *do* reflect on what and how they learn:

4) Does the *kind* of epistemological self-reflection relate to conceptual learning?

In other words, if particular ways of reflecting on the learning of physics appear to help one learn, what are they? To understand fully how students learn physics, we must know the role played by epistemological beliefs.

Answers to these questions are suggested in Chapter 4, and are explored more precisely in Chapters 5 and 6.

### 2.2.4. A more detailed description of epistemological self-reflection

Epistemological self-reflection, again, refers to how students choose to describe what physics they learn and how they learn it, in the context of their Weekly Reports. It is not necessarily a pure representation of epistemological beliefs. In fact, the likelihood that beliefs are dependent on (and intertwined with) the context of their application suggests that there can be no such unambiguous measure. Instead, epistemological self-reflection represents a combination of beliefs and the context in which they exist. This is not a weakness of the methodology, but its key strength. By exploring beliefs in their context, researchers and teachers will better understand their nature and design instruction that takes them into account.

The most relevant part of epistemological self-reflection is, of course, epistemological beliefs. Another other important piece is *self-reflection*, that is, the ability of students to monitor and articulate their own thoughts or views. Although all students in this study were encouraged by their instructor and grader to be thorough when completing their Weekly Reports (see Chapter 3), there is undoubtedly a distribution of self-reflection skills among them. This feature of the context highlights the fact that epistemological self-reflection is about how students *write* about their learning, *not* what
they think about their learning when engaged in other activities. Other measures, in
different contexts, would be expected to yield different results.

The other piece of epistemological self-reflection is related to students’
perceptions about the physics course in which they are enrolled.44 In particular, since the
Weekly Reports are graded assignments, what students write may be influenced by what
the students think the professor or grader wants them to write. This is not a problem. It
takes a certain level of awareness and epistemological sophistication to be able to
reproduce what the professor wants to hear, whether it is strongly believed or not. As such,
epistemological self-reflection is (at worst) a useful approximation of what students would
be expected to write in the absence of such external factors. In Chapter 3, the nature of the
assignment and how it is graded are described in more detail, in order to elaborate on the
context of student reflection.

2.3 Summary

Systematic research in physics education has found that many students come out
of introductory physics courses without having gained a deep understanding of the
important concepts that comprise the discipline. To evaluate student conceptual learning
gains in particular physics courses, a few reliable multiple-choice surveys have been
created. Additionally, research suggests that students’ epistemological beliefs facilitate
conceptual learning, most likely by mediating study strategies. Epistemological beliefs
have not been thoroughly researched in specific areas of physics or in contexts other than
interviews and surveys.

This dissertation aims to fill this gap in the research literature, by measuring
epistemological beliefs about specific physics content in a particular context, that of
regular self-reporting on the learning of physics. It also seeks to measure the development
of epistemological beliefs and their possible connection with conceptual learning. The context of epistemological beliefs studied here is called epistemological self-reflection, and involves students’ beliefs, self-reflection abilities, and perceptions about the course.
ENDNOTES FOR CHAPTER 2


48 Both interviews and surveys, however, can be carefully designed so as to approximate aspects of the class learning environment. For example, Hammer’s interviews involved problem-solving activities akin to the students’ homework assignments.


53 The monitoring of one’s own thinking is usually referred to as *metacognition*. 
CHAPTER 3

STUDENTS’ EPISTEMOLOGICAL SELF-REFLECTION IN INTRODUCTORY PHYSICS

3.1 Overview of this study

The main purposes of this study were to establish the usefulness of Weekly Reports for measuring epistemological self-reflection in this context and to document some of that self-reflection and its apparent dependence on content domain; in essence, to answer Research Question 1.

The Weekly Reports of several students enrolled in introductory physics in the 2000-2001 school year were analyzed for the kinds of epistemological self-reflection they exhibited. In the process, a coding scheme was developed for quantifying their reflection. The coding scheme represents a classification of the kinds of things students write about when reflecting on their learning.

The physics course from which data were collected was designed by Professor Alan Van Heuvelen (of OSU) and Professor Eugenia Etkina (of Rutgers University) and taught by Profs. Van Heuvelen and Jonathan Pelz and Drs. Kathleen Harper and Andrew Heckler. The lab activities for the course were designed by Profs. Van Heuvelen and
Etkina, Professor David Mills (of Monash University), Keith Oliver, and me. The coding scheme for the Weekly Reports was developed by Prof. Etkina and me.¹

3.2 Course description

3.2.1 The Freshman Engineering Honors program at The Ohio State University

The student sample for this study was chosen from the two-quarter physics sequence for participants in the Freshman Engineering Honors (FEH) program at the Ohio State University in the 2000-2001 school year. Participants in FEH take coordinated special classes in physics, chemistry, engineering, and calculus during their first year at OSU. Any engineering freshman identified by the university as an honors student could elect to join FEH; there were approximately two hundred enrolled in 2000-2001. The students in the program were generally very bright; their average ACT Composite score is 29.83, and their average ACT Math score was 31.94. More than 97% of them had taken a year or more of physics in high school.

The physics component of the FEH program consisted of two quarter-long courses. The first 10-week quarter covered introductory mechanics; the second quarter covered electricity and magnetism. Two instructors each taught a section of the course the first quarter (Physics 131E and 131G), and two different instructors each taught a section the second quarter (Physics 132E and 132G). The two hundred students were nearly evenly divided between sections.

Each week students were to attend three 1-hour lectures, two 1-hour recitations, and one 2-hour laboratory. Recitations and laboratories (with about 30 students in each)
were taught by teaching assistants. Course instructors and TAs met weekly to coordinate their instructional goals.

3.2.2 Active learning methods employed in the FEH physics course

Research-based, active-learning strategies were employed extensively in all sections. The “lectures” were mostly interactive; students were often asked to discuss observations and ideas with their neighbors or with the whole class. Interactive computer simulations were also used often. Recitation sections consisted almost exclusively of cooperative group problem-solving sessions, using non-traditional problems that emphasized multiple representations and complex, real-world contexts. Instructional laboratories also made use of cooperative group activities. These methods were developed over several years by Prof. Van Heuvelen (the instructor for 131E) and were based largely on results of research in physics education. Using these methods in previous years, Prof. Van Heuvelen was able to increase dramatically his classes’ average normalized gains on the Force Concept Inventory.

3.2.3 The Investigative Science Learning Environment

In addition to these interactive engagement methods, the course embodied a learning environment that mirrored the investigative character of science. This instructional system, called the Investigative Science Learning Environment (or ISLE) was developed by Profs. Etkina and Van Heuvelen. The ISLE system was created in response to several studies of the skills used by scientists and engineers in the professional workplace. These studies found that college graduates entering the workforce in these fields should know how to learn new things; specifically, that they should be able to use processes of scientific inquiry, solve problems using expert-like strategies, and design investigations and devices. ISLE aims primarily to teach these important skills.
In the ISLE system, physics concepts were not simply given to students and then illustrated with demonstrations. Instead, the idea was for students to construct the physics concepts and laws in each unit for themselves. Students did this by going through a particular cycle of concept acquisition and application. In the first step of this cycle, students observed physical phenomena that were carefully selected by the instructor and presented in lecture. Students were not asked to make any predictions regarding the outcomes of the demonstrations, but the demonstrations were selected so that most students would be able to see a clear pattern in them. One important reason for beginning with observations is that many students need time to see and think about a physical phenomenon before they are able to express their ideas about it with some confidence. Students are often reluctant to make predictions about the outcomes of demonstrations they’ve never seen, as they are often asked to do in many courses that follow misconceptions-based curricula.

After making observations of a phenomenon, students devised qualitative explanations for the patterns they observed, usually working in groups. Next, they designed tests of their explanations, made predictions of test results that would determine if their explanations were adequate, and interpreted the results of the tests (carried out by the instructor in front of the class). Then they identified physical variables, developed quantitative explanations from their observations or from mathematical derivation, and designed experiments to test and find the limitations of these (more precise) explanations. Finally, the students applied their explanations, along with new skills they had developed, to solve analytical problems (in recitation and on homework) and experimental design problems (in lab activities).

These lab activities were designed by me and others especially for this course to complement the lecture and recitation components. Specifically, the activities consisted of
experimental design problems that gave students the opportunity to apply the physics concepts they had constructed in the other parts of class and to learn important design skills. Students were asked to perform certain tasks or find particular quantities by designing their own experiments and executing them using materials and apparatus available in the classroom. They were then required to interpret the results of their experiment and evaluate its design. Examples of these activities are listed in Table 3.1.

<table>
<thead>
<tr>
<th>Mechanics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Newton’s Laws</strong>: Using the equipment provided, design, build, and test an accelerometer that will allow you to measure horizontal accelerations.</td>
</tr>
<tr>
<td><strong>Newton’s Laws and Friction</strong>: Devise and perform an experiment to determine the coefficient of kinetic friction between the [given] truck’s tires and a board on which the truck will be driving.</td>
</tr>
<tr>
<td><strong>Ballistic Motion</strong>: Find two ways to determine the angle of the provided Hot Wheels [toy car] jump. At least one of these methods should require measurements of the car in flight.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electricity and Magnetism</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrostatic Interactions</strong>: Devise and test a method to remove the static charge from a piece of fleece.</td>
</tr>
<tr>
<td><strong>Electric Field</strong>: Devise and test a method to measure the electric field of a static electric charge.</td>
</tr>
<tr>
<td><strong>Electric Fields in Different Media</strong>: Devise one experiment that demonstrates that dielectrics and conductors have similar properties and one that shows they have different properties.</td>
</tr>
<tr>
<td><strong>Magnetic Fields</strong>: Design, build, and test a simple DC motor.</td>
</tr>
</tbody>
</table>

Table 3.1: Examples of the experiment design problems used as laboratory tasks in the FEH physics sequence in the 2000-2001 school year.
By following the cycle described above, the course structure emphasized scientific processes and the proper justification for scientific knowledge. From the epistemological point of view, the goal of the course was to help students construct knowledge following a possible path that a scientist might take and thus help them replace their naïve epistemologies with the epistemology of physics.12

3.2.4 Weekly Reports

Weekly Reports were developed as an instructional tool and implemented elsewhere before being implemented at OSU.13 Each week the FEH students in this study reflected on what and how they learned by writing Weekly Reports. Specifically, students were asked to answer four open-ended questions:

1. What did you learn in lab this week? How did you learn it?
2. What did you learn in lecture and recitation this week? How did you learn it?
3. What questions remained unclear?
4. If you were the professor, what questions would you ask to determine if your students understood the material?

Students responded via the World Wide Web; responses were typically one page long, though many were longer. A screen shot of the Weekly Report submission form used in the 2001-2002 school year is shown in Figure 3.1; it is similar to the one used in 2000-2001. Examples of completed Weekly Reports can be found in Appendix A.

Each week, more than half of the reports from each course section were randomly selected to be graded and given feedback. In this way, each students’ reports were graded at least every two weeks, some even more frequently. Every report was given feedback in the first week.
Weekly Report Editor

Physics 131E/G and 132E/G

Choose a week (during which report is DUE) to edit.

Friday, March 29, 2002 02:00 PM - Friday, April 05, 2002 01:59 PM

1. What did I learn this week, and how did I learn it?
   - What?
   - How?

2. What questions do I still have about the material?

3. If I were the instructor, what questions would I ask or problems assign to find out if the students understood the material?

Figure 3.1: The Weekly Report Editor web form used in the 2001-2002 school year. It is identical to the one used in the 2000-2001 school year except that the earlier year’s form included separate fields for describing what was learned in lab, and in lecture and recitation.
The first-quarter graders were a faculty member who had helped design the course (Professor Etkina) and a graduate student; the second-quarter graders were the course instructors. Graders answered students’ questions (from question 3), and provided comments on questions 1, 2, and 4. The comments to questions 1 and 2 encouraged the students to be precise, clear, and complete in describing what and how they learned, and prompted them to refer to the in-class observations, experiments, and reasoning processes that were intended to help them learn physics. Professor Etkina repeated these comments to all students in person by visiting their classes at least twice during the first quarter; she also reminded them that their reports were being read carefully. The graders’ comments to question 4 emphasized the need for clarity and creativity in coming up with questions that test understanding. Weekly reports were worth 10% of the final course grade; as the students were told, points were deducted from each report for lack of clarity or thoroughness, but not for content.

Reports from the first two weeks of the first quarter were not available for analysis. Most students completed between 13 and 19 reports during the two quarters.

3.3 Development of a Coding Scheme to measure epistemological self-reflection

To characterize and quantify the kinds of epistemological self-reflection seen in the Weekly Reports, a coding scheme was developed. The scheme comprises fourteen codes that refer to what a student says he learned, how he says he learned, and a few other kinds of comments in the reports that had epistemological content. The coding scheme allows for the quantification of epistemological self-reflection and has been used as such in other
studies, including those presented in Chapters 4, 5, and 6. A description of the coding scheme and how it was developed follows.

3.3.1 Utilization of prior research results and of course goals

We began by reading the Weekly Reports of several students (approximately 30), chosen at random from each section of the course. While reading, we took note of what the students wrote that had particular epistemological content. The “epistemological content” we initially had in mind included the dimensions and stages from prior research results (see Chapter 2). In particular, we looked for indications of beliefs about the structure and content of physics knowledge, the source of physics knowledge, and its connection to the world outside the classroom. We also had in mind the course’s special instructional methods and goals, especially predicting and interpreting the results of experimental tests and then applying verified knowledge to solve new problems.

3.3.2 Development of the Coding Scheme

After reading the reports of these students, it was clear that they described learning in a number of different ways. We found, however, that many of these ways of reflecting appeared several times in a student’s reports and also in the reports of other students. For example, most students at one time or another mentioned learning from classroom demonstrations. We gave names to the most common kinds of indications, thus creating our initial coding scheme. This initial coding scheme was used retrospectively to code the reports of our initial set of students’ reports and several reports from other students, to judge its utility. After this first pass, indications of particular codes, as well as interesting indications for which we had no code, were examined closely. As a result of this reconsideration, new codes were added and several of the original codes were redefined, combined with other codes, or eliminated.
Indications of particular codes, found in sentences, groups of sentences, or ideas in a particular report, were called code indications. Most code indications were identified in the first two questions of each report (“What did you learn and how did you learn it?,” in lecture and in lab), but a few did show up in questions 3 and 4.

In the end, fourteen of the codes we developed were chosen; these codes could be placed in one of three categories. We coded indications of what the students said they learned, how they said they learned it, and inferences we could make about their other views about the nature of physics knowledge.

### 3.3.3 The Coding Scheme

Table 3.2 shows our choice of the final coding scheme. It is not merely a tool for future research; because it characterizes most of the epistemological content of students’

| What they say they learned | 1. Formula  
|                           | 2. Vocabulary  
|                           | 3. Concept  
|                           | 4. Skill  
| How they say they learned | 5. Observed phenomenon  
|                           | 6. Constructed concept from observation  
|                           | 7. Reasoned/derived in lecture  
|                           | 8. Reasoned/derived in lab  
|                           | 9. Learned by doing  
|                           | 10. Authority  
|                           | 11. Predicted and tested  
|                           | 12. Predicted, tested, and interpreted  
| Inferences about epistemological beliefs | 13. Applicability of knowledge  
|                                           | 14. Concern for coherence  

Table 3.2: Coding scheme for epistemological self-reflection in Weekly Reports.
Weekly Reports, it is itself a product of research. Descriptions and examples of each code are in the text that follows. Each example is directly from a student’s report, without modification.

**What they say they learn**

Students usually listed the things they learned in a given week, making them relatively easy to identify. Each mention of something learned was considered as evidence that the student thought it was important enough to mention in the report, if not actually an important thing to learn. There are four codes in this category:

1. **Formula** - equations or other mathematical statements, or the implication that the student thinks formulas are important, without elaboration on their underlying meaning

   Example: *We also learned the equations for each type of energy.*

   Example: *We learned Newton’s third law where \( F_{1 \text{ on } 2} = -F_{2 \text{ on } 1} \).*

   This code is similar to the *formulas* aspect of Hammer’s content dimension.\(^{14}\)

2. **Vocabulary** - definitions or other physics language conventions

   Example: *We learned that units of power are called watts.*

3. **Concept** - qualitative descriptions or mentions of concepts, ideas, relationships, or limitations of these

   Example: *We learned that when the sum of forces acting on the object is not zero, there is an acceleration of the object but when they are in the equilibrium the object moves at constant velocity.*

   Like *formulas* (code 1), this code relates to Hammer’s content dimension.\(^{14}\)

4. **Skill** - laboratory design skills, measurement skills, or problem-solving methods and skills, or the implication that the student thinks skills are important

   Example: *We learned that when dealing with a complex force problem, splitting forces into components is a way to solve it.*
How they say they learn

The ways in which students described how they learn are numerous. In reading the reports, we looked for indications of events that convinced the student of something, that made her believe that something was true. As expected, we found mentions of the direct transmission of information from authority (instructors or textbooks), and we also found independent reasoning processes cited for gaining knowledge. Many students also described practice and simple observation as ways of learning. Some also mentioned or implied the role of prediction and testing in constructing understanding, an explicit focus of the course. We ultimately chose to use eight codes that describe indications of how students say they learn:

5. **Observed phenomenon** - observed a physical phenomenon, demonstration, or experiment, without mention of what was learned in the process

   Example: *We observed that the insulation pipes rubbed with natural fur repel each other, if one pipe is rubbed with the natural fur and the other one with synthetic, they attract each other.*

6. **Constructed concept from observation** - learned a concept simply by observing a phenomenon, demonstration, or experiment (including confusing an inference with an observation)

   Example: *Then we observed a ball being compressed on a spring and watching the spring shoot the ball up. This displayed the elastic potential energy of a spring.*

7. **Reasoned/derived in lecture** - followed the reasoning process by which the large class came to a concept or formula, by using prior knowledge and experience, experimental data, logic, mathematics, and/or analogies
Example: *We derived the expression* \( v = ir \) *with simple experiments where a certain current was placed into a circuit and compared with voltage. We then found a linear (sic) relationship between them and found the equation.*

8. **Reasoned/derived in lab** - actively reasoned by oneself or in a small group to come to a concept or formula, by using prior knowledge and experience, experimental data, logic, mathematics, and/or analogies

Example: *We then determined the wiring of a box with 6 light bulbs and 6 switches which had up to three positions. We did this by applying what we know about the properties of loads wired in series and in parallel and observing the circuit’s behavior under different combinations of switches.*

Codes 5 through 8 are, in a sense, a family of codes. The real differences between them are sometimes subtle. Codes 5 and 6 both involve references to observation, but an indication of code 5 does not include any information about what is learned from the observation. Indications of code 6 refer to what is learned, but don’t provide any detail about the process by which learning from the observation occurred. This is where codes 7 and 8 come in. They explicitly refer to what was learned and the reasoning process behind that learning.

9. **Learned by doing** - learned a concept, definition, or formula by using it, or learned a skill or process by performing or practicing it

Example: *I learned about how these concepts relate to circular motion through practicing problems.*

10. **Authority** - told or convinced by instructor, friend, textbook, or other authority figure

Example: *The professor gave us the equation for the law of gravitation.*

This code is similar to the *Source of Knowledge* dimension of Hofer and Pintrich, to Hammer’s *by authority*, and to the *Dualism* stage of Perry and others.
11. **Predicted/tested** - predicted the outcome of an experiment and then conducted or observed the experiment

   Example: *We used the range equation to predict where the ball will land but it landed short.*

12. **Predicted/tested/interpreted** - conducted or observed an experiment to test an idea and interpreted the results of that test

   Example: *We learned that Newton’s second law can be used in combination with kinematics equations. For this we constructed an experiment and made a prediction based on the laws and equations and then found an experimental value. There were two hanging weights (700 g and 500 g) connected by a string across 2 pulleys. We derived how long it takes 700 g mass to hit the ground. We calculated it to be 1.31 s and got the experimental value to be 1.32 s which is close enough to verify that we can combine Newton’s laws with kinematics.*

   Codes 11 and 12 were evident undoubtedly because of the instructional approach used in this course. Still, many students did not mention predicting and testing in their reports. Of those who did, some never described interpreting the results of tests, hence the distinction between codes 11 and 12.

### Inferences about epistemological beliefs

   Many statements made by students in their reports implied certain beliefs about the nature of physics knowledge. Several students mentioned the usefulness of physics knowledge in solving practical problems, and some expressed the expectation that physics knowledge should “make sense” or “fit together” coherently. These indications led to two more codes:

13. **Applicability of knowledge** - indication of belief that physical laws or concepts can and should be applied to solve new problems
Example: We built a horizontal and a vertical accelerometer. The accelerometers were another application of Newton’s second law.

14. **Concern for coherence** - indication of belief that physical laws and concepts fit together into a coherent whole, or at least should agree with each other and with common sense

Example: *The formula has to be right because it obviously explains the entire idea.*

Example: *In order to understand, why there are 2 different equations for gravitational potential energy we derived the simple mgy for close to the surface from the other equation.*

Both codes 13 and 14 relate to Schommer’s *Simple Knowledge*,¹⁷ to Hammer’s *coherence*,¹⁴ and to Redish et al.’s *reality link*.¹⁸ Code 13 shows the belief that physics knowledge is connected to the real world by virtue of its applicability to real world problems. Indications of code 14, on the other hand, show the belief that the real world connection usually takes the form of a physical intuition or analogy, and often that it can be used as a tool for constructing or verifying knowledge.

**Multiple codings**

Some sentences or ideas in reports indicated more than one code, and were therefore coded more than once. For example, consider this example.

Example: *Through a little bit of logical reasoning, and a bit of faith in [the instructor], we arrived at the fact that Work is the Force done on an object times its displacement.*

This statement was coded both with *reasoned/derived* (code 7) and with *authority* (code 10).
What was not coded

Despite our extensive coding scheme, many parts of the Weekly Reports could not be coded. This was usually because we couldn’t tell what the student meant by a particular statement (due to a lack of clarity) or because the statement was not of much epistemological interest. There were also a few statements that were unique; defining an additional code for them would have made the coding scheme unnecessarily cumbersome.

Statements that were too vague to code often included the phrase “learned about.” For example, the statement “Today we learned about Newton’s Second Law” doesn’t reveal very much about the specific content of what was learned. Writing that one learned “through examples of” something doesn’t tell us much, either. Not only is it unclear what the student meant by “examples,” it’s also not obvious in what way the examples were used to learn. Likewise, statements that mentioned learning “from lectures,” “in lab,” and “from reading the textbook” were not sufficiently precise to merit a code. Occasionally, grammatical errors would prevent us from gleaning any meaning from a sentence (or fragment). Despite the graders’ and instructors’ insistence that reports be clear and thorough, many were not.

In addition, many statements were not of interest to this study. Some of these were comments about the logistics of the course or the Weekly Reports. Many, despite what were presumably the students’ best efforts, showed incorrect or sloppy physics. These two examples were coded for their epistemological content, but not for their sloppy scientific language:

Example: A spring in the system may exert potential spring energy.

Example: acceleration is always in the same direction as the force with the largest magnitude.

Some statements were simply incorrect:
Example: *I learned that the change in momentum of a system is equal to the change in impulse of the system.*

Others showed incorrect reasoning. In these two examples, the student clearly was intending to explain a reasoning process that led to new knowledge, but had the wrong idea about what constitutes “proof.”

Example: *A rubber band uses the same equation as the spring in this experiment because a spring contains potential energy when compressed and so does a rubber band. Therefore the same elastic equation is applicable to both.*

Example: *One way to prove that two charges are needed to have a force is to look at the force equation. \(Kq_1q_2/r^2\) shows us that if only one charge exists, then the numerator is equal to zero, thus there is no force.*

A few statements were very interesting, but appeared only very rarely. Since they did not fit any of the existing codes, they were not coded. Both of these examples show a great deal of reflection on the part of the student:

Example: *The most important thing get from this problem is not what the instructor did to find the answer, but why and how she did it, because this is what will be useful in finding answers to future problems.*

Example: *This was very helpful for me, especially, because I am a very visually-oriented person, and I learn things faster when I can see them or see a physical representation of the facts or theories being presented.*

### 3.3.4 Inter-rater reliability

After developing the above coding scheme, a reliability check was conducted. Prof. Etkina and I independently coded the reports of four different students from the first quarter. In every single instance (sentence or group of sentences) in the reports, we agreed on which codes were indicated, although not always on the exact number of indications of
each code. On that number we agreed 90% of the time. For example, we both agreed that the sentence “Like charges repel and opposite charges attract” indicated a concept (code 3). However, one of us initially coded it twice (once for each statement in the sentence) and the other one only once. We ultimately decided that instances like this (in which the two statements were really part of one idea) would be coded only once.

Examples of coded Weekly Reports are shown in Appendix B.

3.4 Domain-dependence of epistemological preferences

The ways in which students preferred to describe what and how they learned (their “epistemological preferences”) are represented by the coding scheme above. Although each student was reasonably consistent in what he or she wrote, clearly preferring to describe some ways of learning over others, each showed a number of different indications (that is, each student’s collection of reports for the 20-week period merited several different codes). Variations in these preferences among different students and on different weeks of the course were examined by counting the number of indications of each code in each week’s reports for each student or for a larger sample of students.

The distribution of codes for different weeks shows that the character of epistemological self-reflection depends somewhat on the week, showing some dependence on the specific physics domain. To demonstrate this, several students were selected from the initial group from which we developed the coding scheme; these were supplemented with others from the class so that there were 15 who were well-distributed in terms of learning pre-test scores and gains. Figure 3.2 shows this distribution for the reports of these 15 students (coded with the final coding scheme) for codes of what they said they learned (a) and for a few select codes of how they said they learned (b). The weeks are numbered from the beginning of the calendar year; hence, the Autumn Quarter comprises
Figure 3.2: Average number of code indications per week in the Weekly Reports of N=15 students for code indications of (a) what they say they learned, and (b) how they say they learned, during Autumn Quarter 2000 (Weeks 41-47) and Winter Quarter 2001 (Weeks 1-9).
Weeks 39-47 and the Winter Quarter Weeks 1-9. Reports from the first two weeks (Weeks 39-40) were not available for analysis.

There were relatively small variations in codes 1, 4, and 10 (Fig. 3.2) and codes 5, 8, 11, 12, 13, and 14 (not shown). The larger variations evident in the other codes reveal the differences in the physics content taught each week and in how it was taught. For example, the sharp drop in the number of indications of codes 3, 6, and 7 seen in Week 45 is consistent with that week’s instructional focus on applying knowledge to solve problems, rather than on learning new concepts by reasoning from experimental data. Likewise, the sustained increase in the number of indications of code 3 in the second half of Winter Quarter (Weeks 5-9) underscores the heavier conceptual emphasis that accompanied learning about magnetostatics and electrodynamics.

An example of the domain-dependence of the reflection of a single student is shown in Figure 3.3. One can see that although this student focused more than the average student on reasoning from prior knowledge or experiment as a way of learning (codes 7 and 8), there were noticeably more indications of learning without reasoning (code 5 in particular) during Weeks 42, 1, and 9. Instruction in those weeks focused on projectile and circular motion, electrostatic forces and Coulomb’s Law, and magnetic flux and electromagnetic induction, respectively. This student appears to have had difficulties interpreting numerous experiments that were shown in lectures during these weeks.

“Zigzag” patterns like those in Figures 3.2 and 3.3 were common to all students in the sample, for all codes. This shows that a variation in epistemological preferences during different weeks of instruction is common. These variations appear to be partly due to the different content and the different instructional focus of each week.
Figure 3.3: Number of code indications per week in the Weekly Reports of one student for indications of codes 5 (*observed phenomenon*) and 7 and 8 (*reasoned/derived*), during Autumn Quarter 2000 (Weeks 41-47) and Winter Quarter 2001 (Weeks 1-9).

### 3.5 Summary and Analysis

The different kinds of epistemological self-reflection shown in this context (and therefore the answer to the first Research Question) are represented by the coding scheme above. They include several dimensions similar to those posited by others, and several more that are (so far) unique to this context.

*Formulas* and *concepts* are certainly dimensions of beliefs that have been seen before in other contexts, but *vocabulary* and *skills* are aspects that have not been explicitly
identified until now. This may be partly due to the unusual context of the Weekly Reports. In interviews and surveys, students are not usually asked to list the things they have learned all in one place; their need to be thorough may have prompted our students to list definitions and problem-solving techniques in addition to equations and concepts. Also, the course instruction may have played a role; there was a greater emphasis on multiple representations, experimental design, and other skills more than in most other physics courses.

The appearance of code 10 (authority) most clearly replicates the results of prior research. It seems that beliefs about acquiring knowledge from authority figures are apparent in students’ written reflections on how they learn physics, not only in the context of interviews about physics or in non-physics settings. Independent learning, the alternative to learning by authority, shows up in indications of reasoning (codes 7 and 8) and interpreting experimental tests (code 12). The specific definition of code 12, however, is certainly a function of the ISLE instructional method; prediction and testing would probably not be mentioned as frequently in a course that did not emphasize it.

The other indications of ways of learning appear to be unique to this context, at least in terms of their usefulness for characterizing student beliefs. Codes 5, 6, 9, and 11 were not identified by others in other contexts. Three of them (5, 6, 11) represent ways of describing learning that are less articulate or complete than corresponding codes 7 and 12. The indication of learning by practicing or repetition (code 9) is another aspect of learning not explicitly identified by other researchers. This may be due to the open-ended nature of the questions in the Weekly Reports. Interview subjects are usually asked specifically about conceptual topics, demonstrations, lectures, or homework problems, but not about whether practicing helps them to learn. Students submitting Weekly Reports have the
freedom to consider the usefulness of this learning activity; many of them did so quite often.

The inferences we made about students’ other beliefs (codes 13 and 14) both relate to the coherence of physics knowledge and its link with the real world. These kinds of beliefs have been identified before in other contexts, in a general sense. Our concern for coherence code (14) replicates this finding. The applicability of physics knowledge, however, is an aspect of the real-world link that has not been specifically coded until now (with code 13), in the context of Weekly Reports. This as well may have to do with the nature of the ISLE instructional system, in which the application of physics laws is the final stage of the learning cycle in each unit.

The coding scheme developed here for analyzing epistemological self-reflection is detailed and complete enough to be useful for future studies using Weekly Reports in similar classes. Some of the codes may also be useful with epistemological self-reflection in other kinds of classes. Despite the fact that the coding scheme applies specifically to this particular context, it is consistent with prior research results and includes some codes that are similar to epistemological dimensions identified by others. However, such a specific measure seems to be required for properly characterizing epistemological self-reflection.
ENDNOTES FOR CHAPTER 3


5 A. Van Heuvelen, personal communication.


8 For example, in a lecture where students construct the idea that for an object to move in circle with constant speed there must be a net force pointed towards the center, students first observe the instructor rolling a bowling ball along a long table (the ball moves with constant velocity) and then tapping it in the direction of motion (the ball speeds up). Then the instructor repeats the experiment tapping the ball in the direction perpendicular to the original direction of motion (the ball follows a parabolic path). The third time, the instructor taps the ball in the direction perpendicular to the direction of motion at every point. Students are asked to construct free body diagrams for each situation and explain the motion of the ball.

9 E. Etkina, personal communication.


12 Of course, it is not possible for students to follow the exact process by which the laws of elementary physics were discovered (over several centuries) by the scientific community. ISLE aims, rather, to teach students one scientific process by which knowledge may be constructed, validated, and applied, and to give students the skills they need to develop new knowledge on their own.


19 Note that learning “from lecture” does not necessarily mean direct transmission of knowledge from lecturer to student, especially in the highly interactive “lectures” of this course. Likewise, there are many ways to gain knowledge from a textbook; one can merely accept whatever is written as true (meriting an authority code), or one can actively study the reasoning process presented in the text.
CHAPTER 4

A COMPARISON OF THE EPISTEMOLOGICAL SELF-REFLECTION OF STUDENTS WITH HIGH CONCEPTUAL GAINS WITH THAT OF STUDENTS WITH LOW CONCEPTUAL GAINS

4.1 Overview of this study

In order to begin exploring the relationship between conceptual learning and epistemological self-reflection in physics, a pilot study was conducted using 12 students from the same course described in Chapter 3. A few of the most successful students in the class and a few of the least successful (as measured by their conceptual learning gains) were compared for the kinds of epistemological self-reflection they showed in their Weekly Reports. In this way, we sought to construct a sort of “existence proof” of the relationship between epistemology and conceptual learning; if there is such a relationship, one would expect to be able to measure a difference between the most successful students and the least successful. Whether or not such a general difference is quantifiable, it would also be useful to explore similarities and differences in describing learning within each of these groups.
The epistemological self-reflection in the students’ reports was compared qualitatively and quantitatively (using the coding scheme described in Chapter 3). Differences were evident between the most successful and least successful students, and other differences were seen among the most successful students. The poorer students tended not to be as articulate as their classmates, and described rote learning or learning from authority rather than by their own reasoning. The better students tended to describe learning in terms of logical (often mathematical) reasoning processes, in terms of making personal and real-world connections to the concepts, or both.

The data from this study were also used to explore the development of individual students’ epistemological beliefs across a two-quarter time period (Research Question 2). Changes in individual students’ reports were examined for possible trends. Only minor changes were detected in the reports of a few students (through qualitative analysis), and only one of them was noticeable in the actual numbers of code indications.

Most of the research presented in this chapter was done in collaboration with Professor Eugenia Etkina.¹

4.2 Student sample selection – high gainers and low gainers

From the half of the class that had the lower FCI pretest scores (that is, those who had the largest chance for gain), we chose the students with the lowest and the highest FCI normalized gains (about ten of each). Normalized gain, as defined in Chapter 2, is the raw gain divided by the maximum possible gain for a given pretest score.² We removed from the sample a few low-gaining students whose scores on the Mechanics Baseline Test³ (given as part of the final exam in the first quarter) were higher than the class average, recognizing the possibility that they had not taken seriously the FCI posttest (which was not part of their course grade). We also removed a few high-gaining students who did not
also achieve high gains on the CSEM in the second quarter, and one low-gaining student whose CSEM gain was very high. In this way, our sample ultimately consisted of six consistent *high gainers* and six consistent *low gainers*, students who were either very successful in learning physics concepts in the course or very unsuccessful.

The normalized FCI gains and normalized CSEM gains for the students in each group are listed in Table 4.1. One can see that even the best low gainers (students 5 and 6) have FCI gains approaching those for classes in the “Interactive Engagement Zone” proposed by Hake; this highlights the fact that these are unusually bright students in an unusually effective class. As it turned out, the low gainers were from all course sections; the high gainers were all from one of the first-quarter sections (131E) and from both second-quarter sections. Thus, although the instructor may have had some effect in the first quarter, the effect disappeared in the second quarter.

<table>
<thead>
<tr>
<th>Student</th>
<th>1</th>
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<th>6</th>
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<th>10</th>
<th>11</th>
<th>12</th>
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<tr>
<td>FCI</td>
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<td>.33</td>
<td>.35</td>
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<td>.80</td>
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<td>.87</td>
<td>.88</td>
<td>.93</td>
</tr>
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<td>CSEM</td>
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<td>.05</td>
<td>.31</td>
<td>.09</td>
<td>.25</td>
<td>.22</td>
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<td>.60</td>
<td>.64</td>
<td>.67</td>
<td>.80</td>
<td>.77</td>
</tr>
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</table>

Table 4.1: Normalized FCI gains and normalized CSEM gains for 6 high gainers and 6 low gainers from the 2000-2001 school year.
4.3 Detailed qualitative analysis of the reports of two low gainers and two high gainers

To provide a solid foundation for understanding the nature of students’ reflection on learning, I describe here in some detail the Weekly Reports of four students chosen because their reports demonstrate the diversity in the reports of the entire sample. The particular modes of reflection shown here are not idiosyncratic, however. They have been replicated by most students at one time or another, and most can be represented by our coding scheme. Morris and Walter (pseudonyms) are low gainers; Theo and Miles are high gainers. The Weekly Report excerpts presented below are exactly as the students typed them.

Morris (student 4)

Morris’s reports were always very brief, receiving an average of only 3.3 codes per week. He was inarticulate, and usually mentioned only what happened in class rather than what and how he learned. Sometimes it was hard to judge if his physics statements were correct because they were so poorly worded.

When Morris did address his learning, he usually did it by listing things that he learned by doing, mostly problem-solving skills. (In fact, of only 23 codings about how he learned, there were 14 indications of Learned by doing.) He used the word “tested” occasionally, but did not say if there was any prediction; he may have used this word just because it was used in class. He described some experiments, but again in light of “learning by doing” rather than for observations or testing. A typical example from the first quarter is below.
1. WHAT DID YOU LEARN IN LAB THIS WEEK?

    We learned that an object may have many components acting on it. There is always a vertical and horizontal component on an object in motion.

HOW DID YOU LEARN IT?

    We constructed a track and raced “hot wheels car” through the track. At the end of the track was a jump that propelled the car upward. This demonstrates that the horizontal component will tell how far the car will travel in a given time. The vertical component will determine the time the car spends in the air.

And from the second quarter:

2. WHAT DID YOU LEARN IN LECTURE AND RECITATION THIS WEEK?

    We attempted to use of anti-derivitive formula to find the electrostatic potential

HOW DID YOU LEARN IT?

    With attempted derivitive problems drawn on the board.

**Walter (student 5)**

Walter was the most verbose low gainer, and wrote more than three times as much as Morris. He mentioned learning problem-solving and laboratory skills more often than anything else, and almost always indicated having learned by doing (code 9) or from authority (code 10). In this typical example from the first quarter, he mentions the ActivPhysics interactive simulation software that was often used in lectures.
HOW DID YOU LEARN IT?

When we were learning about the projectile motion in class this week, the best way for me to understand the problems was to see [Instructor A] working on them via ActivPhysics on the board. The ActivPhysics is very helpful in portraying what actually happens in the experiment. It does not totally help though because it does not give you the equation. This is where [Instructor A] comes in. He uses the ‘known” quantities to find an equation to use and then uses it on the board to help find the answer that ActivPhysics gives us.

…

By [Instructor A] showing the experiments in class and working out the problems, I have been able to grasp some of the things we are learning so far.

It’s clear that Walter was depending much more on the instructor than on himself, unlike most of the high-gain students.

However, there are indications that Walter’s epistemological self-reflection was beginning to change. By the end of the second quarter, he referred less frequently to authority and paid more attention to his own role in learning. For example, he wrote:

HOW DID YOU LEARN IT?

We learned about electric fields by doing problems in class. We looked at electric fields in lecture and [Instructor B] taught us how they worked but what we did in recitation helped me the most. We did ... problems that helped us process what [Instructor B] was teaching us. By us doing the problems in groups nonetheless, it helped all of us figure out
what needed to be done to determine how electric field affects point charges.

Also at this time, he began to indicate that he was looking for coherence in what he learns. None of the other low gainers showed such a change.

Theo (student 11)

This high-gain student didn’t write very much, but was very articulate about what he learned and showed a great deal of thought and personal involvement in learning. Theo often described his attempts to visualize equations and principles, and to integrate them with his existing knowledge. He used derivations and invented analogies, and always looked for cause-effect relationships in equations. This example, from the first quarter, shows Theo’s typical search for connections:

**HOW DID YOU LEARN IT?**

*I learned about f=ma by understanding that if you touch something it starts moving. The kinematics equations alone do not explain this. It makes sense to have a component based on mass and acceleration. The bigger the object is the harder it is to push, and the harder you push the faster it goes.*

Another example shows Theo’s efforts to use his prior knowledge to help construct new knowledge:

1. **WHAT DID YOU LEARN IN LAB THIS WEEK?**

*In lab we learned how to determine the x and y components of a hot wheels car traveling in a form of projectile motion. We figured how to determine the velocity and angles without directly measuring them.*
HOW DID YOU LEARN IT?

We learned this by applying the different kinematics and mathematical equations we learned. We had a starting point and taught ourselves how to get to the end point by just using what we already know.

Theo had a great willingness to think deeply about what he was learning, to extend it to new situations. This example shows that he was aware of the usefulness of analogies for developing understanding and knew that they have limitations:

3. WHAT QUESTIONS REMAINED UNCLEAR?

What causes gravity in general? Is gravity like a magnetic attraction? If so, then is it possible to counter it?

In the second quarter, Theo displayed even more reflection on aspects of knowledge and learning, especially the development of knowledge. As early as the first week of the second quarter, he responded with some interesting questions:

3. WHAT QUESTIONS REMAINED UNCLEAR?

Why was it decided to make the coulomb such a large unit?

4. IF YOU WERE THE PROFESSOR, WHAT QUESTIONS WOULD YOU ASK TO DETERMINE THAT YOUR STUDENTS UNDERSTOOD THE MATERIAL?

What steps were taken to go from having no knowledge to having a general understanding of charged particles?

Miles (student 10)

Like Theo, Miles is a high gainer and understands physics very well. However, his reports are very different from Theo’s. Miles was more articulate; he itemized what he learned and then meticulously addressed how he learned each item. Rather than focusing on his own role in constructing understanding, he addressed how knowledge was
developed by the class and how it was ultimately justified. Also unlike Theo, Miles never asked questions in part 3, and asked only unimaginative questions in part 4.

Miles recognized derivation as a method of acquiring knowledge, and was very adept at following the reasoning processes of the class, as this example shows:

2. **WHAT DID YOU LEARN IN LECTURE AND RECITATION THIS WEEK?**

   *We learned about projectile motion. We learned that in projectile motion, the horizontal component of the velocity is always constant (1). And the total time in the air is determined solely by the vertical component of the velocity (2). So the vertical and horizontal components of the projectile velocity are independent. Also Newton’s 2nd law can be used to solve projectile motion problems (3). We also began to learn about circular motion. In circular motion the force is directed towards the center of the circle (4) and the object in circular motion will want to go in a straight line(5).*  

**HOW DID YOU LEARN IT?**

   *We learned (1) through a simple demonstration where a cart with a vertical ball launcher, launched a ball by a sensor just before it went under a bridge and when the cart came out at the other side of the bridge it was caught in the holder. So the horizontal v was the same as the cart, which was constant, so it was too constant. We proved (2) by doing a problem where a canon is at a given angle and velocity. Then we use the vertical part of the v and found the time and used the time to find the horizontal displacement and that gave the right value. (3) was verified by being given the maximum vertical and horizontal displacements of a projectile. From there we found the angle to aim the canon to get the ball*
into the box. Then we tested our predicted value in the experiment and it worked. For the circular motion (4), we showed that by rolling a bowling ball and then hitting the ball with a hammer, the force, in different uniform directions in order to see which produced circular motion. And hitting towards the center was the one that worked. (5) was proved by having a circular track with a break at a point to see where the ball that was traveling in the circular motion would tend to go without the track and it showed that it would go straight from the last point in the circle.

Right from the beginning, Miles emphasized making predictions, testing them, and interpreting the results (as indicated by code 12). For example, he saw when test results didn’t make sense, and elaborated on possible causes. This emphasis continues throughout the two quarters. He also realized that the application of new knowledge to solving problems and the need for it to fit coherently with existing knowledge can serve as additional tests of its validity. This example refers to an experiment conducted by his lab group:

1. **What did you learn in lab this week?**

   *We learned the difference between static and kinetic friction and how to measure both types of friction.*

2. **How did you learn it?**

   *We found the coefficient of kinetic friction by adjusting the incline of the track so that the monster truck would neither move up nor backwards rather slide, that way it would be kinetic friction. Then with the appropriate force diagram we were able to calculate the coefficient. Then using our experimental value we predicted what hanging weight the truck could pull over a pulley on a lower incline. The prediction and the actual*
value were within 3g so it was sufficient proof. To find the static friction we did the same method as for kinetic expect the truck wasn’t in motion this time. To verify that value for static friction, we predicted what weight the nonmoving truck could start to move, and that value too verified our predictions.

Miles’s reports did not change significantly in the second quarter, but remained excellent examples of very thorough reflection on the construction of, and justification for, new knowledge.

4.4 Quantitative analysis of code indications for the sample

To measure how articulate each student was about how she learned, total numbers of code indications were tallied. Code indications are instances of assigning a particular code to a sentence, a group of sentences, or an idea in a report. The kinds of epistemological self-reflection seen in the reports are represented quantitatively by the numbers of particular code indications in the student’s reports, and are called epistemological preferences. These are compared for high gainers and low gainers in the following sections. The numbers of indications of each code, for each week, for each of the 12 students in the sample are tabulated in Appendix C.

4.4.1 Amount of reflection

The total numbers of codes attributed to the reports of each student (over the 20-week period) are listed in Table 4.2. The high gainers clearly wrote (on average) more about what and how they learned than the low gainers. However, how much they wrote about their learning is not the whole story; what they wrote is just as important, as closer examination reveals.
Table 4.2: Total number of code indications for each high gainer and each low gainer.

<table>
<thead>
<tr>
<th>Student</th>
<th>Low gainers</th>
<th>High gainers</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of indications</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>94</td>
<td>94</td>
<td>169</td>
</tr>
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</table>

Walter (student 5), the verbose low gainer with 216 code indications, frequently focused on authority as a source of knowledge, as described in more detail above (see section 4.3). In fact, his weekly reports were coded for Authority more than twice as much as the reports of any high-gain student. For example, one week Walter wrote, “We were told that an external force acting on a moving object can change the energy of the system.” Meanwhile, the high gainers who wrote relatively little about how they learned (with 134 and 152 code indications) concentrated on their own personal role in constructing knowledge. Recall from section 4.3, for example, Theo (student 11) reporting about a lab activity, “We had a starting point and taught ourselves how to get to the end point by just using what we already know.”

4.4.2 Epistemological preferences

Information about each student’s epistemological preferences was partly determined by normalizing the number of indications for each code. The normalization was done by dividing the number of indications for a particular code by the total number of code indications for that student. This method controls for how much a student writes.
about her learning. High and low gainers’ normalized numbers of indications were compared for individual codes.

Although each student was somewhat consistent in what he or she wrote, clearly preferring to describe some ways of learning over others, each showed a number of different indications (i.e., each student’s collection of reports for the 20-week period merited several different codes). High and low gainers, on average, showed differences in some of the codes and not in others. The average normalized number of indications for each code for the two groups is shown in Figure 4.1.

![Figure 4.1 Average normalized number of indications for each code, for high gainers (N = 6) and low gainers (N = 6). Error bars are one standard deviation in length.](image)
In terms of what the students say they learned (codes 1-4), both groups frequently mentioned concepts and skills and hardly ever mentioned scientific vocabulary. However, the low-gain students mentioned equations and formulas (code 1) much more often than the high gainers.

There were also important differences in how they said they learned. The numbers of indications of codes 7 and 8 reveal that high gainers are much more focused on reasoning as a way of knowing than are low gainers, who mention experiments and observations without explanation (code 5) more frequently than high gainers. Low gainers also indicate learning by doing (code 9) much more often than the high gainers. Low gainers as a whole (not just the verbose student, Walter) have a stronger focus on authority (code 10) than high-gain students. Making predictions, testing them, and interpreting the results was an important emphasis in the course. The related codes (11 and 12) did not appear particularly often, but still indicate an important difference between the groups. High gainers mentioned prediction and test 52 times in all, and went on to describe interpretation of the results on 45 of those occasions. Those low gainers who mentioned prediction and testing, on the other hand, mentioned interpretation only 10 of 32 times.

There was also a large difference in code 14, *Concern for coherence*. The high-gain students much more frequently tried to connect what they were learning to their prior knowledge of physics or the natural world.

### 4.4.3 Favorable and unfavorable code groups

Because particular ways of learning were emphasized in the course, some code indications were deemed more appropriate than others. In this study, we identify epistemologically “favorable” codes as those that indicate student reflection on the construction of their own knowledge: reasoning using observational data or prior knowledge, experimental testing of ideas, concern for coherence (codes 7, 8, 12, 14). We
call epistemologically “unfavorable” the codes that indicate that a student reported observations without mentioning making inferences, relied unduly on authority as a source of knowledge, or described testing experiments without reasoning or interpretation (codes 5, 10, 11). As described in Chapter 3, ways of learning characterized by the favorable codes were emphasized in the course, and are thus considered appropriate subjects of reflection. Unfavorable codes represent ways of learning that are counter to the goals of the course. Although it is sometimes appropriate to learn some things by authority, this was rarely the case in this course.⁵

In addition to looking at codes individually, then, we summed together the code indications about learning that were almost always appropriate in this course (“favorable” codes 7, 8, 12, and 14) and those that were almost never appropriate (“unfavorable” codes 5, 10, and 11). The appropriateness of the other codes about how learning happens depended on the context of what was being learned.

It can be seen right away from the descriptions of four students’ reports presented above (section 4.3) which students tended to reflect in favorable ways and which didn’t. The small amount that Morris wrote was mostly coded as unfavorable. Walter, another low gainer, also reflected on unfavorable ways of learning. The reports of the two high gainers Theo and Miles show a relatively large amount of reflection, but are focused on different, favorably-coded ways of learning.

The raw numbers of favorable and unfavorable code indications for each student are shown in Figure 4.2. It shows that the high gainers and low gainers focus on different aspects while reflecting on how they learned something. High gainers reflect more on the construction of coherent knowledge than low gainers, who focus more on rote learning. An independent-samples t-test shows the differences between high and low gainers’ averages on each of these two composite measures to be significant at the p < 0.05 level.⁶
Figure 4.2: Raw numbers of favorable (a) and unfavorable (b) code indications for low gainers and high gainers, with the mean values for each group.
In general, low gainers didn’t seem to “get” the learning cycle, but often described learning as if they had been in a traditional lecture course.

4.5 Different epistemological preferences among high gainers

The low-gain students tend to reflect on their learning in only one way: by focusing on rote learning and learning from authority. The high gainers, however, appear to reflect on learning in several different ways. In particular, some focus exclusively on logic and reasoning, others on personal, common-sense type connections, and others on a combination of these different ways of thinking about learning.

4.5.1 “Sense-makers,” “logicians,” and others

“Sense-makers”

Two of the high gainers I call “sense-makers” because in their reports they always tried to make sense of the concepts they were learning, and because they often showed their need for an idea to “make sense” before it could be accepted. The way they made sense of them was by connecting the concepts with their own experiences in the laboratory or by mentally reconciling them with other concepts. They often reported the usefulness of “visualizing” a situation in order to construct a deep understanding.

Theo, whose reports are described above (section 4.3) is clearly one of the sense-makers; the other is Scott (student 8). Scott frequently saw the benefit of making personal connections with the concepts he was learning, as this excerpt shows:

1. WHAT DID YOU LEARN IN LAB THIS WEEK?

   In the lab this week we worked with Newton’s second law involving centripetal acceleration. This idea became much more real to me because I saw, measured and worked with it. Also we made our guess
of the tension produced on the rope and got it correct which also made me see that I for certain have the right idea when it comes to understanding and calculating centripetal acceleration. The visualization of the forces that pull an object in a circular direction have become easier for me because of the experience I have had working with it in class and lab.

When listing what he learned in a given week, Scott also sometimes mentioned the epistemological skills needed to justify a new knowledge claim:

2. WHAT DID YOU LEARN IN LECTURE AND RECITATION THIS WEEK?

I also learned how the equations for the energies we are studying were derived and the process to derive them – setting up a situation when only that force is acting and solving for the equation of the energy.

Some of the questions Scott posed in Question 4 as the hypothetical teacher suggested the belief that students should know the empirical justification for physics equations:

4. IF YOU WERE THE PROFESSOR, WHAT QUESTIONS WOULD YOU ASK TO DETERMINE THAT YOUR STUDENTS UNDERSTOOD THE MATERIAL?

Design an experiment to derive equation for the force between the charges. List observations that helped you come up with the equation.

The last two excerpts demonstrate that Scott, despite his strong focus on making personal connections, also understood the importance of derivations for justifying knowledge. Theo rarely mentioned derivations.

“Logicians”

Unlike the “sense-makers,” the “logicians” rarely made personal connections with what they were learning. “Logicians” meticulously describe deriving relationships from basic principles and observations, and often mention prediction and testing.

Two high gainers fall into this category: Miles (whose reports are described in section 4.3) and John (student 12). Miles is clearly more concerned with the logical
reasoning process than with whether or not an idea “makes sense.” So, too, is John. Almost every week, John described the derivations that happened in class in great mathematical detail. He usually neglected to describe any physical experiments, until the last half of the second quarter, when he wrote this:

**HOW DID YOU LEARN IT?**

*By using a wire with a current running through it and by holding a magnet close to the wire, we were able to determine the poles. Using the right hand rule with our knowledge of the direction of the force and current, we were able to solve for the direction of the B field. And since the B field flows from the N pole to the S pole we were able to tell which pole was which.*

This shows his characteristic focus on the reasoning behind any learning activity.

The “logicians” generally did not seek to extend their knowledge beyond the scope of the course. Miles never asked questions of the instructor (in Question 3), and John did only rarely. They understood the logic of the instructional system and never found the need to go beyond it.

**Students who show characteristics of both “sense-makers” and “logicians”**

The other two high gainers, Gloria (student 7) and Harry (student 9), did not fall into either of these two categories. Instead, their epistemological self-reflection showed a mixture of the kinds represented by “sense-makers” and “logicians.” They often mentioned reasoning and experimental tests as ways of learning new knowledge, but also occasionally saw the need for it to fit with their own experiences of the world, though not as frequently as Theo or Scott.
4.5.2 Quantitative differences among high gainers

Some of the differences described above could also be seen in the code indications of the high gainers. Table 4.3 shows raw numbers of code indications for the high gainers, for two particular groups of codes. Theo, one of the two “sense-makers,” mentioned the applicability and coherence of knowledge (codes 13 and 14) more than reasoning or prediction (codes 7, 8, and 12). Scott, as explained above, mentioned both. The two “logicians” clearly focused on reasoning at the expense of personal connections. The other two high gainers showed a sizable number of indications of both varieties.

<table>
<thead>
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<td>76</td>
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<td>Students who show aspects of both</td>
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Table 4.3: Sums of raw numbers of code indications for the six high gainers for codes 7, 8, and 12 and for codes 13 and 14.
The numbers alone suggest that Scott shows aspects of both types of reflection. However, while the indications of codes 13 and 14 in Scott’s reports are mostly about connections with personal experience, Gloria’s and Harry’s reports refer more to the connections among different physics concepts or their applications to analytical physics problems. The failure of codes 13 and 14 to make this distinction highlights the need for in-depth, qualitative analysis of Weekly Reports to accompany any quantification of code indications.7

4.6 Time development of epistemological preferences

The Weekly Reports of the high gainers and low gainers were also examined for evidence of any changes in epistemological preferences over time, which might suggest some form of epistemological development. Changes were noticed in the reports of only three students, as described above. Walter showed a decreased emphasis in the second quarter on authority as a source of knowledge, and focused slightly more on his own role in learning. Also in the second quarter, Theo exhibited slightly more reflection on how knowledge in general is developed. Toward the end of the second quarter, John began to mention in-class experiments rather than only mathematical derivations.

Most of these changes do not show up in the numbers of code indications. For example, John still maintained a focus on reasoning (codes 7 and 8), whether the subject of reasoning was experimental data or mathematical relationships. Only Walter’s decreased focus on authority is noticeable in the numbers of code indications. Figure 4.3 shows how the number of times Walter’s reports were coded for authority (code 10) decreased significantly in the second quarter. None of the other students whose reports were coded showed such a change.
The failure of Weekly Reports, with or without the coding scheme, to detect significant changes in students’ epistemologies could mean one of two things: either students’ beliefs about physics knowledge and learning in this particular class did not change, or the change cannot be measured with Weekly Reports. If the former is correct, and no changes occurred during the course, it’s possible that students had particular epistemological expectations about the course or about physics in general before the first day of class, and that their beliefs “settled” almost instantly, as soon as the instructional method was made clear. Whether they would apply these ideas to learning physics in another kind of course is an open question. It’s also possible that meaningful epistemological change takes longer to occur than two quarters; indeed, Perry found that
for most college students, epistemological development occurs only after three or for years.\textsuperscript{8}

If the development of students’ beliefs is not measurable with Weekly Reports, it may be partly due to the heavy dependence of student reflection on the particular course content on a given week (see Chapter 3); any significant changes may be drowned out by the “noise” inherent in the week-to-week variation of epistemological preferences.

4.7 Summary and Analysis

Our results suggest a relationship between students’ conceptual gains and their epistemological self-reflection, both in terms of how much they reflect (Research Question 3) and what kind of reflection they show (Research Question 4). Most of our low gainers did not write much about how they learned, compared with the high gainers. There were, however, exceptions to this rule: in our small sample, one low gainer reflected on his learning in great detail, while two high gainers did not write a great deal. These high gainers nonetheless were able to reflect on the construction of knowledge by following the reasoning process in class or by making knowledge relevant to their personal experience. They also tried to make coherent sense of the material by asking profound questions. These exceptions might mean that it may not be the quantity of reflection but its quality that matters, and that student questions might provide worthwhile insights into their epistemological preferences.

Analysis of specific codes provides more evidence for a possible correlation between conceptual gains and epistemological views. Low conceptual gainers were more likely than high gainers to mention learning activities that are epistemologically less desirable: learning formulas without heeding their conceptual implications, learning from authority, and predicting and testing without interpretation. High gainers, however, more
frequently referred to reasoning and interpretation of experimental results, and showed more concern for the coherence of knowledge than their counterparts.

What’s more, high gainers demonstrated different patterns of epistemological self-reflection; some succeeded in the course by focusing only on logical reasoning, and others concentrated on making personal connections with the concepts. Both of these modes of reflection are epistemologically appropriate, and either of them appears to be adequate for achievement in physics, at least for these students.

These results imply that “good” students have knowledge that is appropriate epistemologically as well as conceptually, and that they are better at reflecting on what they learn and how they learn it. Research aimed at verifying these tentative relationships, and making use of larger and more diverse student samples, is presented in the following two chapters.
ENDNOTES FOR CHAPTER 4


5 In this class, the instructor made a special effort to avoid “content delivery” and to engage students in the construction of concepts (from observations or relationships to other concepts) and then by testing the concepts experimentally. Physical notions were not defined before students constructed their meaning. Mathematical relationships were either discovered as patterns in data or derived from previous relationships. All relationships were tested experimentally.

6 An independent-samples t-test is the most commonly used statistical method for evaluating the differences in means between two groups. It assumes a normal distribution of the dependent variable (in this case, favorable or unfavorable code indications) within each group (high and low gainers). The p-value associated with a t-test is the probability that the difference in means is due to chance; standard p-levels in education research are 0.10 and 0.05. For more information, see J. Cohen and P. Cohen, *Applied Multiple Regression: Correlation Analysis for the Behavioral Sciences*, 2nd ed. (Erlbaum, Hillsdale, NJ, 1983).
Indeed, more codes could be added to the coding scheme to make it more precise. However, adding too many codes would make the scheme cumbersome and inefficient. The more codes one added, the closer they would approximate purely qualitative analysis.

CHAPTER 5

EPISTEMOLOGICAL SELF-REFLECTION VERSUS CONCEPTUAL LEARNING GAINS: A CORRELATIONAL STUDY

5.1 Overview of this Study

The apparent differences in epistemological self-reflection between students with very high conceptual learning gains and those with very low gains (described in Chapter 4) imply that there is a relationship between epistemological beliefs and conceptual learning. To see if this relationship can be detected in a larger population, one with a wider distribution of conceptual gains, a study was conducted with 30 students from the FEH physics sequence in 2000-2001. Their Weekly Reports were coded and conceptual gains calculated.

The correlation between the amount of epistemological self-reflection and conceptual learning gains (Research Question 3) was calculated using simple linear regression. Using multiple linear regression (MLR), correlations between the different kinds of self-reflection and conceptual gains were calculated (Research Question 4). The amount of reflection does not appear to be related to conceptual gains, but the kind of
reflection does. This is evidence for the conjecture that epistemological beliefs play an important role in conceptual learning in physics.

5.2 Study design

5.2.1 Student sample selection

From the FEH class described in Chapter 3, thirty students were selected in the following manner. There were 152 students for whom there existed matched pretest and posttest scores on the FCI and CSEM. These matched data were arranged in order of FCI pretest score. From this list, every fifth student was selected, resulting in a sample of 30 students whose FCI pretest scores were distributed in the same way as the entire class’s scores. As it turned out, the sample’s scores on the CSEM pretest and normalized gains on both the FCI and CSEM were also distributed in the same way as the class’s scores (i.e., they had nearly the same means and standard deviations; see Table 5.1). For these reasons, the sample is believed to be representative of the entire class in terms of the physics concepts they knew coming into the class and their conceptual gains during the class, as measured by the respective surveys.

As you can see in Table 5.1, two students earned negative normalized gains on the FCI in the first quarter. In the case of student 30, it is a very large negative normalized gain (-100%), yet reflects an insignificant change in score (this student got 29 out of 30 questions correct on the pretest, and 28 correct on the posttest). For this reason, student 30 was considered an outlier and was excluded from the analysis of the Autumn Quarter data. All 30 students were included in Winter Quarter.

The Weekly Reports of the students in the sample were collected and coded using the coding scheme described in Chapter 3. The numbers of indications of each code were
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| Sample mean   | 16.8       | 0.50     | 9.7          | 0.50     |
| Sample std. dev. | 5.9       | 0.36     | 4.7          | 0.19     |
| Class mean    | 16.6       | 0.53     | 10.2         | 0.51     |
| Class std. dev. | 5.9       | 0.30     | 4.1          | 0.21     |

Table 5.1: FCI and CSEM pretest scores and normalized gains for the student sample (N = 30), with mean values and standard deviations for the sample and for the subset of the entire class for which matched scores exist (N = 152).
calculated for Autumn and Winter Quarters for each student, as well as numbers of favorable and unfavorable code indications for each quarter (see Chapter 4) and the total numbers of code indications for each quarter. These numbers are shown in Table 5.2.

There are two reasons why data for Autumn and Winter Quarters have been recorded and analyzed separately. First, the courses in these quarters covered topics that are different in ways that might be important. Newtonian mechanics deals primarily with macroscopic phenomena that can be viewed directly, whereas the learning of concepts in electricity and magnetism relies to a larger extent on inferences about microscopic phenomena. This difference may prompt students to think about learning these topics in different ways.

Second, the FCI and the CSEM are very different types of tests, as described in Chapter 2. The FCI is a diagnostic instrument that addresses very specific conceptions about a small number of specific topics (namely, Newton’s Laws of Motion). The CSEM, on the other hand, is a more general survey of a wide variety of ideas in electricity and magnetism. While both have been validated as instruments for measuring at least some aspects of a class’s conceptual learning,\(^1\) they each measure different aspects of that conceptual learning. Since this study seeks to relate conceptual learning to epistemological beliefs, differentiating these aspects of conceptual learning is prudent.

### 5.2.2 Probing the effect of the amount of reflection

The study described in Chapter 4 showed that, with a few exceptions, high gainers tend to write more when reflecting on their learning than low gainers. To see if this trend is evident among students with less extreme conceptual gains, the total numbers of code indications in the reports of the students in the present study were correlated (using simple regression) with their gains each quarter. In this way, I seek a more precise answer to Research Question 3. A significant positive correlation would imply that the mere act of
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Table 5.2: Numbers of indications each quarter of individual codes, favorable and unfavorable code groups, and all codes together for the students in the sample.
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<td>16</td>
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<td>10</td>
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<td>17</td>
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<td>24</td>
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<td>15 2</td>
<td>82</td>
<td></td>
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<tr>
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<td>9 0</td>
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<td>26</td>
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<td>8 2</td>
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<td></td>
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<tr>
<td>27</td>
<td>1 0 1 8 9 0 6 4 3 1 1 0 0 0 1 0</td>
<td>7 1</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>3 0 7 8 4 4 0 0 3 0 0 0 0 0 2 0</td>
<td>2 4</td>
<td>31</td>
<td></td>
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<td>29</td>
<td>8 1 1 2 6 1 3 0 7 1 1 5 2 1 0 0</td>
<td>16 1</td>
<td>74</td>
<td></td>
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<tr>
<td>30</td>
<td>16 1 3 2 1 5 0 3 1 6 2 2 2 0 0 0 1 0</td>
<td>18 0</td>
<td>88</td>
<td></td>
</tr>
</tbody>
</table>
reflecting on one’s learning of physics in Weekly Reports is somehow related to that learning. A negative correlation (which would be contrary to what the pilot study of Chapter 4 suggests) might mean that reflection adversely affects learning, perhaps by taking time away from other forms of studying. The lack of a correlation would imply that how much a person reflects on learning in Weekly Reports is not important for learning.

5.2.3 Probing the effect of the kind of reflection

Whether or not the amount of epistemological self-reflection is related to conceptual gains, the question of whether the kind of reflection is related (i.e., Research Question 4) is an important one. The results of Chapter 4 suggest that certain ways of describing learning are conducive to learning physics concepts better: reasoning independently from prior knowledge or experimental data, making connections between physics concepts and personal experience, and conducting experimental tests of hypothetical explanations. Also, less favorable ways of describing learning seem to have the opposite relationship with conceptual gains, including undue reliance on authority and observations without reasoning or inference. Describing learning by doing (code 9), while not inherently unfavorable, was much more frequent in the low gainers’ reports than in those of the high gainers.

To see if epistemological self-reflection does have an effect on the conceptual gains of the larger, more diverse student sample in the present study, the numbers of indications of each code were correlated (using multiple linear regression, or MLR) with their conceptual learning gains. For each quarter, the linear model included one dependent variable (FCI or CSEM normalized gain) and 14 independent variables (numbers of indications of each code in each quarter); that is, \( k = 14 \).

If there is an effect, it would be useful to know if it can be explained by considering the relative amounts of favorable and unfavorable ways of describing learning.
in the students’ reports. Since high gainers seem to describe learning in different, favorable ways (see Chapter 4), any individual code would not be expected to correlate strongly with gain. Summing the favorable code indications into a single variable might produce a better correlation and therefore have more explanatory power. Again using MLR, the numbers of favorable and unfavorable code indications were regressed on normalized gain for each quarter (thus, $k = 2$).

The grouping of favorable and unfavorable codes leaves several codes out of the analysis, and thus it might fail to account for much of the possible effect. In addition, it weights equally the codes in each group, whereas they may have differential effects. If this is the case, and the favorable and unfavorable code groups don’t explain the variation in conceptual gains, then what does? To find out, a stepwise regression procedure (described in detail below) was carried out with all 14 codes, resulting in a regression equation with only a subset of codes ($k < 14$). This determines the ways of describing learning that have the largest effects on conceptual gains, and the relative strengths of those effects.

5.2.4 Statistical considerations

Multiple linear regression (MLR)

As in all studies that make use of MLR, each of the calculations described above resulted in a regression equation. Each regression equation represents the linear combination of the given independent variables $x_n$ that best approximates the values of the dependent variable $y$:

$$y = \sum_n c_n x_n$$

where the $c_n$ are constant coefficients to be determined. In this case, the dependent variable is the normalized gain on the FCI or CSEM, and the independent variables are numbers of code indications (of particular codes or of favorable and unfavorable code groups). In each
case, the squared multiple correlation coefficient $R^2$, if statistically significant, represents the amount of variation in the dependent variable that is accounted for (or that "can be explained") by the variation in the best linear combination of the independent variables. A particular collection of independent variables, with the associated regression equation and $R^2$ value, is called a model. The full model includes as independent variables the numbers of indications of each of the 14 codes.

**Standardized scores**

In this study, standardized scores (also called *z*-scores) were used in all regression calculations. For a given (dependent or independent) variable $x$ with mean $\mu$ and standard deviation $\sigma$, the corresponding standardized scores are defined as:

$$z = \frac{x - \mu}{\sigma}$$

This creates a uniform scale for the variables in which each has a mean of zero and a standard deviation of one. With standardized scores, the width of the scale of each variable will not influence our judgement of the strength of any relationship between them.

**Adjusted $R^2$**

One effect of the large number of predictor variables ($k = 14$ in the full model, for example) is that the explained variance $R^2$ calculated from the sample data overestimates the actual value of $R^2$ in the population from which the sample was taken. This is because the process of fitting the regression model to a sample routinely capitalizes on chance properties of the sample. It is likely that the independent and dependent variables will appear to be somewhat related, even if they are not related at all.

If the value of $R^2$ in the population is zero (i.e., there is no relationship), the expected value of the sample $R^2$ is $k/(N-1)$, where $k$ is the number of independent variables. Bias also occurs when there is a real relationship. This bias is larger the greater the
number \( k \) of independent variables, and smaller for larger sample sizes \( N \). The estimate of the population \( R^2 \) routinely calculated from sample statistics is called \( \textit{adjusted} \) \( R^2 \), or \( \tilde{R}^2 \), and is given by:

\[
\tilde{R}^2 = 1 - (1 - R^2) \frac{N - 1}{N - k - 1}
\]

This provides a better estimate of the strength of the correlation in the population, and is used in each model in this study.

**Multicollinearity**

Another important effect of the large number of predictors is \( \textit{multicollinearity} \). Multicollinearity is the degree to which the independent variables are mutually correlated. Even when the predictors together account for a large amount of variation in the dependent variable, each one separately may not explain significant variation due to multicollinearity. In this situation, some of the variation accounted for by one code may also be explained by other codes. One would expect there to be significant intercorrelations among the 14 codes simply because 14 is a large number of variables, and also because each code goes naturally with some codes and not with others. For example, it would make sense for students to report learning skills (code 4) by practicing them (code 9) rather than by predicting and testing the results of experiments (codes 11 and 12).

Extensive multicollinearity can cause problems with interpreting the effects of individual predictors, because individual regression coefficients will be nonsignificant (even if \( R^2 \) is significant). To determine the relative importance of particular codes, then, a “best subset” of codes was created via stepwise regression for each quarter, as described below. In this way, a few codes can be combined to explain a maximum of the variation in conceptual gains, with a minimum of redundancy in the variation they explain individually. Including fewer codes also decreases the bias in \( R^2 \) due to chance (as explained above). To
determine the *overall* effect of epistemological self-reflection, however, the full model is justified. Multicollinearity does not affect the significance of $R^2$ or the predictive power of the regression equation.

**5.3 Results – Autumn Quarter 2000**

**5.3.1 Amount of reflection**

For the 29 students included in the analysis for Autumn Quarter, a scatterplot of FCI normalized gain (from Table 5.1) versus total number of code indications in the Weekly Reports from Autumn Quarter (from Table 5.2) is shown in Figure 5.1. The correlation coefficient between gain and total code indications is $r = -0.098$. The result is not statistically significant ($p = 0.61$).

The lack of a significant correlation between the amount of epistemological self-reflection and conceptual learning gain shows that for most students, how much they write in their Weekly Reports about their learning is not an indication of how well they learn physics concepts. The trend discovered in the reports of students with extreme gains (the high and low gainer of Chapter 4) may either be a fluke, or a trend that exists only for these students (whose conceptual gains would represent the “tails” of the distribution of gains in the class).

**5.3.2 Kind of reflection**

Because the amount of reflection has no measurable effect on gains, the multiple regression analyses conducted in this section use raw numbers of code indications as independent variables, rather than the normalized numbers used at one point in Chapter 4. These independent variables for Autumn Quarter, after being standardized (see above), are labeled $a_1, a_2, \ldots, a_{14}$ (“a” for Autumn). The regression equations that represent the linear
Figure 5.1 FCI normalized gain vs. total number of code indications for Autumn Quarter 2000 (N = 29). The linear regression line corresponds to $r = -0.098$.

models will therefore have the form:

$$< g >_{FCI} = \sum_{n} c_n a_n$$

where the regression coefficients $c_n$ are assumed to be constants.

**Is there an effect?**

The full model was created by regressing the 14 numbers of code indications for Autumn Quarter on FCI normalized gain. The model satisfied tests of linearity and normality, justifying the use of MLR. The model yielded a significant multiple correlation
coefficient of $R = 0.853$ ($p = 0.04$), which gives $R^2 = 0.727$. The estimate of the squared multiple correlation for the population is $\tilde{R}^2 = 0.454$.

This result shows that when taken together, the kinds of epistemological self-reflection measured by the coding scheme account for more than 70% of the variation in the sample’s FCI gains, and can be expected to account for nearly half of the variation in the population’s FCI gains. Thus, there is indeed a significant effect on gains due to an optimal linear combination of numbers of code indications.

**The effect of favorable and unfavorable kinds of reflection**

The numbers of favorable and unfavorable code indications (as defined in Chapter 4) were regressed on normalized FCI gain. This two-predictor model satisfied linearity and normality criteria. The model yielded a significant multiple correlation coefficient of $R = 0.521$ ($p = 0.02$), which gives $R^2 = 0.272$. The estimate of the squared population multiple correlation is $\tilde{R}^2 = 0.216$. The standardized regression equation for FCI normalized gain $<g>_{FCI}$ is

$$< g >_{FCI} = 0.217f - 0.449u$$

where $f$ and $u$ represent the numbers of favorable and unfavorable code indications, respectively. The significance of the coefficients of $f$ and $u$ are $p = 0.21$ and $p = 0.01$, respectively.

These results indicate that clustering code indications into favorable and unfavorable groups accounts for less than half of the variation in gains that the full model explains. This means either that some of the excluded codes have a significant effect, or that codes within each group do not have equal effect, or both. Indeed, the questionable statistical significance of $f$’s coefficient may be a sign that the different favorable ways in which high gainers describe their learning deserve different weights. Also, the comparison
of high and low gainers in Chapter 4 showed a large difference in code 9 (learned by doing), which was not in either the favorable or unfavorable code groups.

Despite the fact that much of the variation is not accounted for by this model, it does account for some of it (approximately 22% in the population). What’s more, the regression coefficients provide more detailed information about the effects of the different code groups. The unfavorable codes appear to have twice the effect of the favorable ones (as indicated by the relative magnitude of the respective coefficients), but the poor significance of one of the coefficients makes this result questionable. Still, the favorable codes have a positive relationship with FCI gain, whereas the unfavorables have a negative one, as expected.

**Best subset regression for explanatory and predictive validity**

Although the full model result shows that epistemological self-reflection is an important factor related to conceptual learning, it doesn’t show the specific kinds of reflection that are the most important. The model that used the two code groups gets more specific, by distinguishing favorable codes from unfavorable codes, but fails to account for much of the variation in FCI gain seen in the full model. To address these issues, a stepwise regression technique was employed to determine a regression equation involving a best subset of the 14 codes.

Beginning with one independent variable, variables were added to and removed from the model one at a time, based on specific criteria. The first variable added was the one with the largest simple correlation with FCI normalized gain. In each successive model, the variable that caused the largest change in $R^2$ over the previous model was added, so long as the change in $R^2$ and the resulting regression coefficients were significant at the $p < 0.10$ level. A variable would be removed if the significance of its regression coefficient climbed above $p = 0.10$. Insignificant coefficients, like multicollinearity, don’t adversely
affect the strength of the regression or its predictive validity, but they make it difficult to interpret the effects of individual predictors. The stepwise procedure was halted when all regression coefficients in the model were significant and when the addition of any remaining variables would not add significantly to $R^2$. The same process was used for the Winter Quarter data to model the distribution of CSEM gains. Table 5.3 shows each step of the procedure for data from the Autumn Quarter, with the corresponding values of the adjusted $R^2$ at each step.

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>Reason</th>
<th>$\tilde{R}^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$a_5$</td>
<td>Strongest simple correlation with $&lt;g&gt;_{FCI}$</td>
<td>0.323</td>
</tr>
<tr>
<td>2</td>
<td>$a_9$</td>
<td>Produced highest significant change in $R^2$</td>
<td>0.482</td>
</tr>
<tr>
<td>3</td>
<td>$a_3$</td>
<td>Produced highest significant change in $R^2$</td>
<td>0.563</td>
</tr>
</tbody>
</table>

Table 5.3: Stepwise procedure for determining the best subset of codes ($a_1, \ldots, a_{14}$) for predicting FCI normalized gains of $N = 29$ students from Autumn Quarter 2000.

The best subset model thus includes the variables corresponding to numbers of indications of code 3 ($a_3$), code 5 ($a_5$), and code 9 ($a_9$), and estimates that 56% of the variation in FCI normalized gains in the population can be explained by this model. This is more than the 45% estimated by the full model, most likely because of the substantial
multicollinearity inherent in the latter. This best subset model satisfies the criteria for normality and linearity.  

The relative effects of the specific predictors can be seen in the regression equation:

\[ <g>_{\text{FCI}} = -0.562a_5 - 0.510a_9 + 0.319a_3 \]

The strongest effects are from codes 5 and 9, and both of them have negative effects on FCI gain. Code 5 (observed phenomenon) is an unfavorable code, so it’s not unexpected that it have a negative coefficient. Code 9 (learned by doing), as explained above, is not unfavorable, but does have a strong negative correlation with gain both in this study and in the comparison of high and low gainers in Chapter 4. Code 3 (concepts) has a smaller, positive effect.

The meaning of the best subset model should be reiterated. Just because only three codes appear in the model, it does not mean that other codes are unimportant or fail to explain any variation in FCI gains. Rather, the variation explained by the absent codes is, for the most part, accounted for by the three that are in the model. By having only a few codes as predictors, \( R^2 \) has much less bias than in the full model. The result, in this case, is that \( \hat{R}^2 \) is much larger, and thus the linear combination of three codes above explains more of the variation in the population than the full model does.

### 5.4 Results – Winter Quarter 2001

#### 5.4.1 Amount of reflection

A scatterplot of CSEM normalized gain (from Table 5.1) versus total number of code indications in the Weekly Reports from Winter Quarter 2001 (from Table 5.2) is shown in Figure 5.2.
Figure 5.2 CSEM normalized gain vs. total number of code indications for Winter Quarter 2001 (N = 30). The linear regression line corresponds to $r = -0.017$.

The correlation coefficient between gain and total code indications is $r = -0.017$. The result is not statistically significant ($p = 0.93$). This replicates the result from the Autumn Quarter data, that students’ amount of epistemological self-reflection is not related to their conceptual learning gains.

### 5.4.2 Kind of reflection

Because the amount of reflection has no measurable effect on gains in the Winter Quarter (like in Autumn), the multiple regression analyses conducted in this section again
use standardized raw numbers of code indications as independent variables. These independent variables are labeled $w_1, w_2, \ldots, w_{14}$ (“w” for Winter). The linear models are represented by regression equations of the form:

$$< g >_{\text{CSEM}} = \sum_n k_n w_n$$

where the regression coefficients $k_n$ are assumed to be constants.

**Is there an effect?**

The full model satisfied tests of linearity and normality, justifying the use of MLR. The model yielded a significant multiple correlation coefficient of $R = 0.830$ ($p = 0.05$), which gives $R^2 = 0.690$. The estimate of the squared population multiple correlation is $\hat{R}^2 = 0.400$.

This result is very similar to the result from Autumn Quarter, in which the full model was regressed on FCI gain. In this case, the kinds of epistemological self-reflection measured by the coding scheme account for nearly 70% of the variation in the sample’s CSEM gains, and can be expected to account for 40% of the variation in the population’s CSEM gains. Thus, there is indeed a significant effect on gains in both quarters due to an optimal linear combination of numbers of code indications.

**The effect of favorable and unfavorable kinds of reflection**

As with the Autumn Quarter data, the numbers of favorable and unfavorable code indications were regressed on normalized gain (this time, CSEM gain). This model also satisfied linearity and normality criteria. The model yielded a significant multiple correlation coefficient of $R = 0.485$ ($p = 0.03$), which gives $R^2 = 0.235$. The estimate of the squared population multiple correlation is $\hat{R}^2 = 0.179$. The standardized regression equation for CSEM normalized gain $<g>_{\text{CSEM}}$ is

$$< g >_{\text{CSEM}} = 0.216 f - 0.386u$$
where $f$ and $u$ represent the numbers of favorable and unfavorable code indications, respectively. The significance of the coefficients of $f$ and $u$ are $p = 0.23$ and $p = 0.04$, respectively.

Again, the results from Winter Quarter match closely those from Autumn Quarter, even down to the poor significance of the coefficient of $f$. These code groups account for less than half of the variation in gains explained by the full model, possibly for the reasons elaborated above (in section 5.3.2).

As with the Autumn Quarter data, this two-predictor model does account for some of the variation in gains (in this case, approximately 18% in the population). The regression coefficients provide the same information about the effects of the different code groups as before: the unfavorable codes appear to have a larger effect than the favorable ones. And as expected, the favorable codes have a positive relationship with CSEM gain, whereas the unfavorables have a negative one.

**Best subset regression for explanatory and predictive validity**

For the same reasons explained above (in section 5.3.2), a stepwise regression technique was employed to determine a regression equation involving a best subset of the 14 codes for Winter Quarter. The procedure used was identical to the one used with the Autumn Quarter data, except that the variables used were from the Winter (CSEM normalized gains, and the code indications $w_1, w_2, \ldots, w_{14}$).

Table 5.4 shows each step of the procedure, with the corresponding values of the adjusted $R^2$ at each step.

The best subset model thus includes the variables corresponding to numbers of indications of codes 14, 10, 4, 7, 12, and 13 (a different set from that for Autumn Quarter). The large effect of code 9 (which was initially in the model but later dropped) appears to be accounted for by the six codes that were ultimately included. It’s estimated that 54% of
Table 5.4: Stepwise procedure for determining the best subset of codes ($w_1, w_2, \ldots, w_{14}$) for predicting CSEM normalized gains of $N = 30$ students from Winter Quarter 2001.

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>Reason</th>
<th>$\bar{R}^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$w_9$</td>
<td>Strongest simple correlation with $&lt;g&gt;_{CSEM}$</td>
<td>0.134</td>
</tr>
<tr>
<td>2</td>
<td>$w_{14}$</td>
<td>Produced highest significant change in $R^2$</td>
<td>0.207</td>
</tr>
<tr>
<td>3</td>
<td>$w_{10}$</td>
<td>Produced highest significant change in $R^2$</td>
<td>0.260</td>
</tr>
<tr>
<td>4</td>
<td>$w_4$</td>
<td>Produced highest significant change in $R^2$</td>
<td>0.315</td>
</tr>
<tr>
<td>5</td>
<td>$w_9$</td>
<td>Significance of regression coefficient &gt; 0.10</td>
<td>0.288</td>
</tr>
<tr>
<td>6</td>
<td>$w_7$</td>
<td>Produced highest significant change in $R^2$</td>
<td>0.369</td>
</tr>
<tr>
<td>7</td>
<td>$w_{12}$</td>
<td>Produced highest significant change in $R^2$</td>
<td>0.492</td>
</tr>
<tr>
<td>8</td>
<td>$w_{13}$</td>
<td>Produced highest significant change in $R^2$</td>
<td>0.536</td>
</tr>
</tbody>
</table>

The variation in CSEM normalized gains in the population could be explained by this model. This is more than the estimated 40% explained by the full model, most likely because of the substantial multicollinearity inherent in the full model. This best subset model satisfies the criteria for normality and linearity.3

The relative effects of the specific predictors can be seen in the regression equation:

$$<g>_{CSEM} = 0.471w_{14} - 0.422w_{10} - 0.548w_4 + 0.781w_7 - 0.491w_{12} - 0.247w_{13}$$

All coefficients are significant at the $p < 0.10$ level. The unfavorable code 10 (authority) has a negative effect on CSEM gain, and the two favorable codes 14 (concern for...
coherence) and 7 (reasoned/derived in lecture) have positive effects. Codes 4 (skills) and 13 (applicability of knowledge) appear to be negatively related to gain.

What’s unexpected is the negative relationship seen in the favorable code 12 (predicted/tested/interpreted). Looking more closely at the raw data (Tables 5.1 and 5.2), it appears that most students didn’t mention prediction and testing at all during Winter Quarter, and those who did mentioned it only once or twice (with the exception of student 4, who appears to be an outlier on this variable). Since code 12 is indicated infrequently, and in fact has no significant simple correlation with CSEM gain, it may be in the equation only to provide for the effects of excluded variables with which is is intercorrelated.6

5.5 Summary and Analysis

The two main conclusions of this study contrast with each other: How students reflect on their learning is strongly related to their ability to learn physics concepts, but how much they reflect is not. The total number of code indications from each student’s collection of Weekly Reports was correlated neither with FCI gains in Autumn Quarter nor with CSEM gains in Winter Quarter. A significant portion of the variation in these gains, however, could be explained by a collection of codes, each of which represents a particular way of reflecting on knowledge and learning in introductory physics. Each regression model analyzed in this study is summarized in Table 5.5.

It now appears that in the pilot study of Chapter 4, the two high gainers who reflected very little and the one low gainer who reflected quite a bit are in fact more the rule than the exception. Although they did not reflect on learning as much or as little as their fellow high or low gainers, the ways in which they reflected were more in line with those in their group. This is consistent with the present study, in which particular combinations of ways of describing learning were found to be strongly linked with learning gains.
<table>
<thead>
<tr>
<th>Quarter (dependent variable)</th>
<th>Model</th>
<th>Variable(s)</th>
<th>Standardized regression weights $\left( c_n \text{ or } k_n \right)$</th>
<th>$R$ *p &gt; 0.10</th>
<th>$\hat{R}^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Autumn</strong> (FCI normalized gain)</td>
<td>Simple</td>
<td>$a_1 + a_2 + \ldots + a_{14}$</td>
<td>N/A</td>
<td>$r = -0.098^*$</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Full</td>
<td>$a_1, a_2, \ldots, a_{14}$</td>
<td>[not calculated]</td>
<td>0.853</td>
<td>0.454</td>
</tr>
<tr>
<td></td>
<td>Favorable &amp; unfavorable code groups</td>
<td>$f = a_2 + a_8 + a_{12} + a_{14}$</td>
<td>0.217*</td>
<td>0.521</td>
<td>0.216</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$u = a_2 + a_{10} + a_{14}$</td>
<td>-0.449</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Best subset</td>
<td>$a_5$</td>
<td>-0.562</td>
<td>0.781</td>
<td>0.563</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$a_9$</td>
<td>-0.510</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$a_3$</td>
<td>0.319</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Winter</strong> (CSEM normalized gain)</td>
<td>Simple</td>
<td>$w_1 + w_2 + \ldots + w_{14}$</td>
<td>N/A</td>
<td>$r = -0.017^*$</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Full</td>
<td>$w_1, w_2, \ldots, w_{14}$</td>
<td>[not calculated]</td>
<td>0.830</td>
<td>0.400</td>
</tr>
<tr>
<td></td>
<td>Favorable &amp; unfavorable code groups</td>
<td>$f = w_2 + w_8 + w_{12} + w_{14}$</td>
<td>0.216*</td>
<td>0.485</td>
<td>0.179</td>
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Table 5.5: Summary of the simple and multiple linear regression models used to compare epistemological self-reflection with conceptual learning gains. Regression weights and correlation coefficients indicated by an asterisk (*) are not statistically significant.
Students were encouraged by the graders of the Weekly Reports to be thorough and complete, but not to describe learning in any particular way. That was the student’s choice. The grade pressure just to write something intelligible and relevant may have had similar effects on students who ended up with conceptual gains that were high, low, or in-between, as they ended up writing (on average) the same amount. What they wrote appears to be the important factor in explaining gains, as indicated by the large squared multiple correlations estimated for the population by the full model each quarter.

In Autumn Quarter, a combination of codes 3, 5, and 9 explains most of the relationship with conceptual gains. In Winter, the best subset included codes 4, 7, 10, 12, 13, and 14. The real effects of the other codes each quarter (demonstrated by the result of using the full model) are accounted for by these combinations. Learning concepts by reasoning or making connections (codes 3, 7, and 14) indicates higher conceptual gains, and describing learning by observing without making inferences or by authority (codes 5 and 10) has the opposite effect, replicating the results of Chapter 4. The unexpected negative effect of code 12, as explained above, may be due to the very small number of times it was indicated.

Codes for skills, learning by doing, and the applicability of knowledge (4, 9, and 13) were not considered favorable or unfavorable, but each indicated lower conceptual gains in the best subset models. This may be because lower gainers, when introduced to the new skills, problem-solving methods, and applications that were unique to this course, focused on them to the exclusion of other, conceptual aspects of learning represented by other codes. This reduced focus on concepts might explain these students’ mediocre conceptual gains.

In interpreting the results of this study, I am not claiming that particular kinds of epistemological self-reflection cause conceptual learning. Correlations do not indicate
causality. They do, however, indicate that some kind of relationship exists. It’s possible that the arrow of causality goes both ways in this case; it may be more accurate to say that the right epistemological beliefs facilitate conceptual learning. As described immediately above, what might be the wrong beliefs (indicated by a reduced focus on concepts) may have adversely impacted some students’ learning of concepts. What’s clear is that students who tend to describe learning in particular ways are those who tend to have a particular level of success at learning physics concepts.
ENDNOTES FOR CHAPTER 5


2 Normalized numbers were used in the study in Chapter 4 to control for the effect of the different amounts of reflection seen in the reports of high and low gainers.

3 Normality refers to the distribution of residuals; a residual is the difference between a value of the dependent variable and the corresponding value predicted by the regression equation. Linearity refers to the relationship between the residuals and the predicted values of the dependent variable.

4 That is, $f = a_7 + a_8 + a_{12} + a_{14}$, and $u = a_5 + a_{10} + a_{11}$.

5 That is, $f = w_7 + w_8 + w_{12} + w_{14}$, and $u = w_5 + w_{10} + w_{11}$.

6 This is not unexpected. The stepwise regression process does not completely eliminate multicollinearity, it just minimizes it.

7 In interpreting the effects of particular codes, it’s important to note that they are not completely independent variables, particularly the “How they say they learn” codes (5-12). When a student writes that she learned something in one way, that part of the assignment is over; she probably won’t explain how she learned the same thing again. In each instance of reporting how something is learned, the choice of one method usually precludes others. With so many codes, however, this effect is quite small.
CHAPTER 6

THE USE OF EPISTEMOLOGICAL SELF-REFLECTION INFORMATION TO PREDICT CONCEPTUAL LEARNING GAINS

6.1 Overview of this Study

Chapter 5 describes a model for epistemological the self-reflection seen in one physics class and its relationship to conceptual learning. The model has two parts: a description of the kinds of reflection seen in these students’ Weekly Reports (as represented by the coding scheme) and a mathematical formulation of the connection between reflection and conceptual learning (as represented by the different regression equations).

To begin to determine the universality of this model, it was applied to a different physics class. Each part of the model was applied and examined carefully in this new context. The coding scheme was evaluated by applying it to the students’ Weekly Reports, and the regression equations were evaluated by using them to predict conceptual learning gains from numbers of code indications. Each of these two parts of the study are described in the two following paragraphs.
The statistical correlation between kinds of epistemological self-reflection and conceptual learning gains determined for the first class (in Chapter 5) leads to the conjecture that it is possible to predict the second class’s conceptual gains from their numbers of code indications, using the best subset regression models of the first class’s gains and code indications. If it exists, the ability to predict a student’s success at learning physics concepts by measuring her epistemological self-reflection would be further evidence of a connection between the two constructs, and would also provide instructors with meaningful and timely feedback about student learning that would indicate when intervention is necessary and allow them to take appropriate action. In order to see whether such a prediction is possible, a study was conducted with thirty students enrolled in the FEH physics sequence in the year following the studies of Chapters 3, 4, and 5 (i.e., 2001-2002). The Weekly Reports of these students from the second year were coded, and their conceptual gains were predicted using the regression equations from the best subset models of the 2000-2001 data; the prediction was unsuccessful.

The other aspect of evaluating the initial model of Chapter 5 is a determination of whether the coding scheme for Weekly Reports developed from the 2000-2001 FEH data can be applied to the reports of students from a similar population. Although the FEH physics courses in these two academic years were alike in many respects, they differed in a few ways, including how the Weekly Reports assignment was administered (as explained below). Because of these differences, the coding scheme was not particularly effective at categorizing the reflection of the students in the second year. This, in turn, may have prevented the successful prediction of their conceptual gains from their coded reports. In this way, the model that successfully characterizes epistemological self-reflection and its relationship with conceptual learning in the first year does not fit the data from the second year.
6.2 Study design

6.2.1 Student sample selection

Thirty students were selected from the FEH physics sequence in 2001-2002. This year’s FEH cohort was very similar to the previous year’s. It achieved an average ACT Composite score of 29.99 and a Math score of 31.11 (compared to 29.83 and 31.94, respectively, for the first year). Again, practically the entire class had taken at least one year of high-school physics.

All thirty students were chosen from just one of the three Autumn Quarter lecture sections, because it was the only section taught using the ISLE system (see Chapter 3) and the only section for which Weekly Reports were graded regularly. As in Chapter 5, the selection was made so that the distribution of pretest scores and gains for the sample was similar to that of the entire class, ensuring a representative sample (see Table 6.1).

6.2.2 Year-to-year course differences

Although the student populations in the two different years were nearly identical, the courses themselves were not. In the first year, the two creators of the ISLE learning system (Professors Van Heuvelen and Etkina - see Chapter 3) played a much larger role in the teaching of the course during the first year than in the second year. Professor Van Heuvelen taught a section of the course in the first quarter of the first year, and both Professors Van Heuvelen and Etkina carefully guided the other instructors during that quarter and the following quarter. While one of these instructors taught the course in the second year, it was without the explicit guidance of the ISLE developers. In addition, the creators of the lab activities (including me) taught the labs and trained the other lab teaching assistants in the first year; the lab TAs in the second year were not involved in the development of the course.
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Table 6.1: FCI and CSEM pretest scores and normalized gains for the student sample (N = 30) from the 2001-2002 academic year, with mean values and standard deviations for the sample and for the subset of the entire class for which matched scores exist (N = 47).
More importantly, the Weekly Reports were administered differently. Students in the second year received much less encouragement to reflect carefully on their learning in their reports or to read the feedback they received on previous weeks’ reports. During Autumn Quarter of the second year, reports were graded every week, but each student received feedback on average only once every three weeks (compared to feedback every other week in the first year after the first week, during which every student was given feedback). The frequency of feedback was even less Winter Quarter 2002. What’s more, the graders the second year were new and did not receive the same training as during the first year, and grading styles were very different among graders.

The Weekly Report questions themselves were slightly different the second year. Instead of separate response fields for describing what was learned in lab and in lecture and recitation, students were given the single question, “What did you learn this week?”, followed by “How did you learn it?” The last two questions were unchanged from the previous year (see Fig. 3.1).

6.2.3 Data collection and analysis

The sampled students’ Weekly Reports were collected and coded using the coding scheme described in Chapter 3. The numbers of indications of each code were calculated for Autumn and Winter Quarters for each student, as well as numbers of favorable and unfavorable code indications and the total numbers of code indications for each quarter. These numbers are shown in Table 6.2.

Predicted FCI and CSEM normalized gains for each student were calculated using the best subset models, with parameters determined in Chapter 5 for the data from the previous year. Numbers of code indications for the second-year sample students were substituted into the corresponding regression equations (for Autumn and for Winter), producing the predicted gains. Actual FCI and CSEM normalized gains (see Table 6.1)
### Number of indications - Autumn Quarter

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Table 6.2: Numbers of indications each quarter of individual codes, favorable and unfavorable code groups, and all codes together for the students in the sample from the 2001-2002 year.

122
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were calculated from pretest and posttest scores, and were compared to the predicted gains using the technique of cross-validation, a simple correlation between actual and predicted gains.

6.3 Results

6.3.1 Use of the Coding Scheme

The coding scheme developed from the previous year’s class proved difficult to apply to the Weekly Reports of the current, second-year class. Throughout both quarters, the reports had a very different character than those from the previous year. Specifically, this year’s students were allowed to be much more vague about how they learned, even though they were generally very thorough in describing what they learned. Many more of the statements they made mentioned learning “from examples,” “in lecture,” or “from reading the textbook,” and as such were not specific enough to be coded with the coding scheme developed during the first year. Examples of other vague, uncodable statements in reports about learning include:

Example: (2) and (6) were learned by the instructor's explanation. (3), (5), and (7) were discovered through explanation and class discussion. We learned (4) through a demonstration on a computer program.

Example: We looked at examples of batteries.

Example: We just came up with a list of things that would influence the force on a wire and from the list came the equation.

At the beginning of the second year, students were given a “model” of a completed Weekly Report. This model report was originally written and submitted by Miles, one of the “high gainers” from the previous year, and consisted of numbered lists.
of what Miles learned and how he had learned it (see Chapter 4). As a result of this example, most students numbered what they learned and how they learned it in their own reports. However, they did not usually replicate Miles’s logical style or his careful explanations of how concepts had been learned. Often many of them would simply use the “How did you learn it?” field to add more detail to their descriptions of what they learned.

Even where the coding scheme could be applied, the numbers of particular code indications reflected the general lack of specificity of these reports compared with the previous year. Codes for the more specific learning activities of predicting, testing, and application (codes 11, 12, and 13) were seldom found, showing up only 22% as often as in the first year. Code 8, reasoned/derived in lab, was indicated only once, probably because there was no longer a specific question in the Weekly Reports about learning in lab (as there was in the first year when the coding scheme was created).

As a result of the students’ numbering of items in their reports, simple descriptions of observations that otherwise would have been coded as observed phenomenon (code 5) were coded as constructed concept from observation (code 6) instead, because their numbering system clearly indicated the concept to which they must have been referring. Accordingly, the number of indications of code 6 is 60% larger in the second year than in the first. Because the reports were so vague, the number of indications of code 5 is also slightly higher in the second year.

To further illustrate how reports in the second year were generally more vague than during the first year, Figure 6.1 contains excerpts of two typical Weekly Reports, each from an average-scoring student from each of the two years. They both describe the learning of magnetic induction, which took place near the end of the second quarter of the course each year. You can see that although the student from the second year was very
(a) Student 21 (2000-2001)

WHAT DID YOU LEARN IN LECTURE/RECITATION THIS WEEK?

-MAGNETIC FLUX: Change in it induces voltage and current, and several things factor into it. The derivative of flux gives the voltage induced at a current time. Flux is the integral of (dot product) B*dA – makes sense.

HOW DID YOU LEARN IT?
Bflux was initially observed when a wire connected to a galvanometer was looped up and moved with respect to a magnet. We saw that some voltage resulted, and that it mattered on the speed of the magnet, the strength of the Bfield, the rate of change of the Bfield, the area of the wire loop, orientation, etc. The relationships concurrent with the before mentioned give rise to the equation Bflux=NBAcosO. Note that A was a vector which points perpendicular to the plane. Observation: if the magnetic flux changes at a constant rate, then the voltage stays constant. Conclusion: the voltage resulting from magnetic flux is the rate of change of magnetic flux, or the derivative of it.

(b) Student 19 (2001-2002)

WHAT DID YOU LEARN THIS WEEK?
C.) The rule for induced current: change is magnitude of the magnetic field, a field must be perpendicular to the loop, and the flux depends on how fast or the rate of change. D.) When an iron bar is placed within a coil and then made part of a circuit, the iron causes the magnetic dipoles to align which will induce a bigger current. E.) To get current: a changing B causes an E or a change in Volts (which is called an induced Ein...sort of like a voltage). Ein depends on the angle, B, N, A, and the rate of change. The rule is Ein = -d/dt [NBA cos angle] (that’s the angle between the Area and the B field). F.) BA cos angle = the magnetic flux thru each turn of the coil (and flux is to be though of as an amount at a particular time). Because of this rule, Ein also = -d/dt[N*flux]. G.) The reason for the minus sign in the Ein rule is explained by Lens Law: The induced voltage Ein cause an induced current Iin that produces an induced magnetic field Bin that opposes the changing flux (or Bex). Graphically, the V induced across the loop in the negative derivative of the flux.

HOW DID YOU LEARN IT?
C.) Discussed in lecture after observations were taken on what does and doesn’t produce a flux. D.) This was observed when the iron bar was placed inside the coil and the light was then able to shine, unlike before when there wasn’t enough current to light the light. E.) and F.) These equations were just given to us, and then we proved them with our observations. G.) This is the explanation for the (-) in the equation and we just discussed this in lecture to verify that it really should be there.

Figure 6.1: Excerpts of Weekly Reports on the learning of magnetic induction, from Week 9 in the second (Winter) quarter, from (a) student 21 from the 2000-2001 school year, and (b) student 19 from the 2001-2002 school year.
thorough in listing what she learned (Fig. 6.1(b)), her description of how she learned it doesn’t provide much detail; it’s impossible to tell what she means by “discussed in lecture” or “proved them with our observations.” The student from the first year (Fig. 6.1(a)) did a much better job of explicitly tying his conclusions to experimental results.

6.3.2 Predictive validity

The ability of the coding scheme to predict the conceptual learning gains of these students was examined using the best subset models determined from the previous year’s data. FCI normalized gains were predicted by putting the Autumn numbers of indications of codes 3, 5, and 9 for each student into the best subset regression equation determined in Chapter 5 for that Autumn Quarter:

\[ <g>_{\text{FCI}} = -0.562a_5 - 0.510a_9 + 0.319a_3 \]

CSEM normalized gains were predicted from the Winter numbers of indications of the codes in the best subset model for the Winter Quarter (i.e., codes 4, 7, 10, 12, 13, and 14):

\[ <g>_{\text{CSEM}} = 0.471w_{14} - 0.422w_{10} - 0.548w_4 + 0.781w_7 - 0.491w_{12} - 0.247w_{13} \]

The validity of these predictions was then tested using cross-validation. For each quarter, simple linear regression was used to find the degree of correlation between the predicted gains and the actual gains for the thirty students from the present year (2001-2002). The resulting correlation coefficients for Autumn and Winter are \( r_A = 0.01 \) and \( r_W = 0.08 \), respectively. Neither result is statistically significant. This means that normalized gains for students in the 2001-2002 year cannot be successfully predicted using the coding scheme and the regression equations determined with data from the 2000-2001 year.
6.4 Summary and Analysis

To summarize, Weekly Reports were collected from a sample of thirty FEH physics students from the 2001-2002 school year. The course in this year was somewhat different; the ISLE system of learning may not have been applied as rigorously, and the students were not given as much feedback and encouragement on their Weekly Reports as during the previous year. Their reports were generally more vague than in the preceding year, and it was difficult to code the second-year reports using the first-year coding scheme. The numbers of code indications were used with the best subset regression equations from the previous year’s data to predict their conceptual learning gains, but the prediction was unsuccessful.

In other words, the model developed with the first year’s data does not fit data from the second year. The problem may be with one assumption of the linear model, which is represented with these general equations:

\[ <g>_{FCI} = \sum_n c_n a_n \quad \text{and} \quad <g>_{CSEM} = \sum_n k_n w_n \].

This model assumes that the regression coefficients \( c_n \) and \( k_n \) are constants that depend only on the numbers of specific code indications. It now appears, however, that these coefficients also depend on other, unmeasured parameters, as illustrated below:

\[ c_n = c_n(\{a_n\}, x, y, \ldots) \quad \text{and} \quad k_n = k_n(\{w_n\}, x, y, \ldots). \]

What are these parameters? It’s not clear, but clues to their identity can be found by looking more closely at the applicability of the coding scheme to the Weekly Reports from the second year. Since the linear model makes use of numbers of code indications, it is only as good as the coding scheme used to analyze the epistemological self-reflection seen in the reports. The second year’s reports, as described above, show very little epistemological self-reflection compared with what occurred the previous year. It appears,
then, that the coding scheme developed from the 2000-2001 data, while very useful for categorizing and quantifying the kinds of reflection found in that year’s reports, is not appropriate for coding the reports of this year’s class. It can’t analyze reflection where there isn’t any reflection to analyze.

Why, then, were the students so vague in their Weekly Reports? The most likely explanation is the great difference in how the reports were integrated into the course. In the second year, students were encouraged much less often to reflect meaningfully on their learning and therefore didn’t write as much. They were given less feedback on their reports, and were given less motivation to read and think about the feedback that they did receive.

This suggests that achieving meaningful reflection on one’s learning is more difficult than one might initially think. Simply assigning Weekly Reports, providing a model report, and grading them for clarity and completeness may not be enough to get most students to reflect deeply. Just as with solving challenging physics problems, you can’t simply tell students to do it for them to succeed – they need practice, regular feedback, and encouragement. The importance of feedback for meaningful learning has been documented by Black and Wiliam.¹

The unmeasured parameters that may impact the quality of epistemological self-reflection appear to be the frequency and quality of grading and feedback on Weekly Reports and the amount of encouragement students are given to pay attention to that feedback. If a universal model for the relationship between epistemological self-reflection and conceptual learning is to be successful, it must consider the effects of these parameters.
ENDNOTES FOR CHAPTER 6

CHAPTER 7

CONCLUSION

7.1 Summary of the Dissertation

In addition to conceptual understanding and problem-solving skills, the development of students’ epistemological beliefs is becoming more widely recognized as an important goal for introductory physics courses. We expect students to gain an understanding of the structure of physics knowledge; to see that it is a coherent system of concepts synthesized by individual learners from careful observations of the real world, rather than a loose collection of facts handed down by experts. To help students develop appropriate epistemological beliefs, they must first be better understood, both by students and by instructors. Research must take into account both the specific content domain about which students have these beliefs and the particular context in which students express them. Very little research on epistemological beliefs in physics has been carried out.

The studies in this dissertation measure aspects of students’ epistemological beliefs in a variety of conceptual areas in introductory physics, and in a novel context: regular self-reporting by students on their knowledge and learning. By completing Weekly Reports, first-year honors engineering students enrolled in a special physics
course at Ohio State reflected on what they learned and on how they learned it, which I refer to as epistemological self-reflection. The goals of this dissertation are to measure epistemological self-reflection in this special context, to see if students’ epistemological development can be traced, and to begin to develop a universal model for the possible relationship between epistemological beliefs about physics and student success at learning physics concepts.

Chapter 3 details the initial study in which the epistemological self-reflection of students in the 2000-2001 FEH class was analyzed. This resulted in the development of a coding scheme for categorizing and quantifying the many different kinds of reflection seen in these students’ Weekly Reports.

The exploratory study of Chapter 4 includes an analysis of the Weekly Reports of six high gainers and six low gainers from the class described in Chapter 3. The reports were analyzed qualitatively, and also quantitatively, using the coding scheme developed in Chapter 3. The low gainers tended to describe their learning in terms of learning from authority or by practicing solving problems. The high gainers more frequently described learning by reasoning or by making personal connections to the concepts. The individual character of each student’s self-reflection did not change significantly over the course of two quarters of instruction.

A larger study was conducted with thirty students from the same class, in order to determine more completely an initial model for epistemological self-reflection and its connection to conceptual learning. It is described in Chapter 5. The students’ Weekly Reports were coded using the coding scheme, and the numbers of indications of each code were tabulated for each report. These numbers were then compared with the students’ conceptual learning gains, using techniques of linear regression analysis. While the amount of epistemological self-reflection (as determined by the total number of code
indications for each student) does not correlate with conceptual gain, the *kind* of reflection does. Generally speaking, the more favorable ways of describing learning are positively correlated with gains, and the less favorable ways are negatively correlated. *Learning by doing* (code 9) is also negatively correlated with gain.

In an experimental test of the universality of this model, the combinations of particular codes found (in Chapter 5) to have the strongest correlation with conceptual learning gains were used to predict the gains of thirty students from the 2001-2002 school year, using codings of their Weekly Reports as predictors. Chapter 6 details this study. These combinations, however, failed to predict students’ gains, largely because the lack of extensive self-reflection in these students’ reports made it difficult for them to be coded. This dearth of reflection is probably due to the reduced amount of feedback and encouragement students were given on their reports in this course. Put another way, *the model developed with the first year’s data does not fit data from the second year*, probably because it failed to consider a number of unmeasured parameters related to how the Weekly Reports were administered in the second year’s class.

### 7.2 Answers to the Research Questions

#### 7.2.1. Epistemological beliefs in specific domains and contexts (Research Question 1)

1) What kinds of epistemological self-reflection do students exhibit in Weekly Reports?

In writing about what they learned in their physics class, students mentioned formulas, concepts, laboratory and problem-solving skills, and physics vocabulary and conventions. Analyzing students’ answers to the question, “How did you learn it?,” we found that students focused almost exclusively on experimental evidence, logical
reasoning, practice, and authority. They also indicated common sense, the applicability of knowledge, and its coherence as factors affecting their learning. This allowed us to develop 14 codes for characterizing three aspects of student reflection (what they learned, how they learned it, and inferences about beliefs). This coding scheme, presented in Chapter 3, is a representation of our findings.

As described in Chapter 3, the findings represented by many of the codes in our coding scheme replicate those of prior research on epistemological beliefs, particularly Hammer’s description of the beliefs of students in introductory physics classes. Reflection on knowledge and learning in terms of formulas, concepts, reasoning, authority, and coherence (codes 1, 3, 7, 8, 10, and 14) has been seen before in other contexts. What seems to be unique to the contexts of Weekly Reports and the ISLE learning system employed in this course is reflection on physics vocabulary, skills, practicing, predicting, testing, and application (codes 2, 4, 9, 11, 12, and 13).

The fact that it was possible to code student reflection on the construction of knowledge with a limited number of codes shows a general consistency across different students and diverse physics content. This finding suggests the possibility of using the same coding scheme to analyze student interviews and classroom interactions to compare findings of different studies. As the results of Chapter 6 indicate, care must be taken to ensure the students are reflecting meaningfully on their learning.

7.2.2. Development of epistemological beliefs (Research Question 2)

2) Can students’ epistemological development be traced and/or explained throughout the time of a physics course?

As described in Chapter 4, significant changes in students’ epistemological preferences could not be traced through the two quarters. Only minor changes were detected in the reports of three students, and in only one case can a change be seen in the
numbers of indications of a single code (see Fig. 4.3). Either the students’ beliefs did not change very much, or such a change is not measurable using these Weekly Reports.

The possibility that there is almost no change in students’ epistemological beliefs during the course does not necessarily mean that they held these beliefs strongly before entering the course. It may be that in their epistemological self-reflection, students were responding to the particular system of instruction employed in the course from the very first day. In that case, their styles of reflection would have “settled” right away, appearing in their very first Weekly Reports. This instant epistemological shift that occurs when students first experience the way a particular class is run has been noticed by others:

Of course, classroom contexts may also vary. …. It is possible to change, very quickly, how students participate in our physics classes. Students who arrive on the first day expecting a blackboard lecture replete with equations, who would appear to hold beliefs that scientific knowledge is formal, absolute, and received from authority, may by the end of the period be participating in heated debate, behaving as as if they believe their own ideas and experiences matter. This does not reflect a sudden, global change in their epistemological beliefs; it reflects a local change in the context of the classroom, which engenders in students a more productive epistemological mode.²

7.2.3. The relationship between epistemological self-reflection and conceptual understanding (Research Questions 3 and 4)

3) Does the amount of epistemological self-reflection relate to conceptual learning?

Although the high gainers of Chapter 4 tended to reflect more on their learning than their low-gaining classmates, the trend was not reflected in the larger, more diverse sample of Chapter 5. When encouraged consistently to reflect on how they learn physics, most students will do so, regardless of how well they learn physics. This result has implications for instruction that are discussed in the next section.
4) Does the kind of epistemological self-reflection relate to conceptual learning?

The results of the analysis of Weekly Reports using the developed coding scheme suggest that different students do in fact reflect differently on the construction of knowledge in the same instructional environment. For example, even if the course is structured in an epistemologically favorable way and students do not receive new concepts from authority, some of them still think that they learn from authority.

Analysis of specific codes suggests a strong relationship between conceptual gains and particular epistemological views. In the pilot study of Chapter 4, low conceptual gainers were more likely than others to mention learning activities that are epistemologically less desirable: learning formulas without heeding their conceptual implications, learning from authority, and predicting and testing without interpretation. High gainers, however, more frequently referred to reasoning and interpretation of experimental results, and showed more concern for the coherence of knowledge than their counterparts.

These trends were replicated in the correlational study of the larger, more diverse sample presented in Chapter 5, justifying a more complete model for the connection between epistemology and conceptual learning. A focus on learning concepts in favorable ways was correlated strongly with conceptual gain, while the reporting of learning from authority and by observing without making inferences had strong negative effects on gain. Learning skills, learning by practicing, and references to the applicability of knowledge each had a negative relationship with conceptual learning; as explained in Chapter 5, this may be due to a reduced emphasis on concepts in these students’ self-reflection.

More importantly, the size of the correlation is remarkable. Regression models using the best subsets of the fourteen codes produce adjusted R-squared values of greater than 50% (see Table 5.5). In other words, more than half of the variation in conceptual
learning gains in the population are expected to be explained by variations in the particular ways of learning represented by the codes in these best subset models. It appears that “good” students have knowledge that is appropriate epistemologically as well as conceptually, and that they are better at reflecting on what they learn and how they learn it. This implies that appropriate epistemological self-reflection facilitates conceptual development.

The inability to predict the conceptual learning gains of the students in the second year (Chapter 6) indicates that the model developed in Chapter 5 is not complete. A number of unmeasured parameters may have had an effect on the quality of the Weekly Reports from the second year and therefore on the applicability of the coding scheme to these data. Initial attempts to identify these parameters suggest that there is a need to encourage reflection consistently if epistemological beliefs are to be measured in this context at all. Reflecting on one’s learning is a difficult endeavor, one that seems to require extensive feedback and practice. For this reason, great care must be taken by researchers and instructors when they wish to measure epistemological beliefs effectively.

7.3 Implications for Instruction

7.3.1 Epistemological beliefs are important for instruction

For many teachers of physics, the development of appropriate epistemological beliefs in their students is an important goal of instruction. For others, epistemology may not be as important. These teachers, however, would still be wise to encourage appropriate and thorough epistemological self-reflection, because it may facilitate conceptual learning. Instruction can and should take advantage of this connection. Quality reflection on knowledge and learning may be an end in itself, or it may be a means to an end. The
importance of good epistemological beliefs for learning physics has been documented in the research of others in different contexts.\textsuperscript{1,3,4}

It’s important to emphasize that the reflection that teachers encourage must be of an appropriate nature. Results presented in this dissertation indicate that it is not the amount of epistemological self-reflection that is connected with learning physics, but rather the existence of favorable kinds of reflection. Reasoning from experimental data, derivation, and recognition of the coherence of physics knowledge are ways of reporting learning that better seem to facilitate that learning.

### 7.3.2 Getting students to reflect

The first step in improving students’ epistemological self-reflection is simply to get them to reflect. Awareness of one’s knowledge and learning comes before awareness of one’s beliefs about knowledge and learning.\textsuperscript{5} Students should be encouraged to reflect on a regular basis on how they construct content knowledge and acquire skills. Careful implementation of Weekly Reports or a similar assignment is one way to do this. Again, the results of this dissertation suggest that it’s important to provide students with regular feedback and encouragement to reflect thoroughly.

Although Weekly Reports are a time-consuming way to encourage content-based reflection on knowledge and learning, the same goal can be achieved by putting similar questions in homework assignments or in laboratory reports. This also encourages students to see their reflection as an integral part of doing science.

### 7.3.3 Improving students’ epistemological beliefs

Getting students to reflect in epistemologically appropriate ways can be challenging, but it can be made easier if they are encouraged to make use of the logic and common sense that they already have. One approach might be to ask content questions that call for the justification of knowledge, such as, “How can you convince a friend that
two objects always act on each other with forces that are equal in magnitude?"6 One can also design questions that will indirectly encourage students to reflect on how they know what they know by asking them to make a decision, for example: “You have a motorized toy car. How can you find out if it moves with constant velocity, constant acceleration, or changing acceleration?"6 These are examples of open-ended questions that do not have a single solution; they are the kinds of questions that help to promote high-level thinking skills, including epistemological and self-reflection skills.5

These and other approaches have been used in physics courses taught using the ISLE learning system, including having students design tests of their explanations and having them pose questions themselves about the justification of knowledge. Although the effects of these approaches have not yet been carefully measured, they have been used in these courses and may in fact contribute to the development of sophisticated epistemological thinking.

Whatever method of instruction a teacher uses, it’s important that it discourage rote learning and learning from authority, and that it emphasize more scientific learning processes: reasoning, prediction, testing, looking for logical connections between concepts, etc. Since epistemological thinking is a crucial part of doing science, it should be encouraged at every stage of learning science.

7.4 Questions for Future Research

The answers to the research questions presented in this dissertation comprise an important step in understanding students’ epistemological beliefs in introductory physics, by underscoring the importance of regular self-reflection for eliciting these beliefs, and by discovering a connection between these beliefs and the learning of physics concepts. Like any research, however, this work raises more questions than it answers. Of particular
importance are questions about the effective measurement of epistemological beliefs and questions about the connection between epistemological beliefs and conceptual learning. Only by answering these questions with careful research can a complete model be developed and extended.

7.4.1 Measuring epistemological beliefs

Effective measurement of epistemological beliefs is very difficult. Students generally don’t just declare, “This is what I believe about knowledge and learning.” As explained in Chapter 6, merely asking them to reflect on how they learn isn’t sufficient either. Whether implemented solely for research purposes or as part of instruction, epistemological reflection exercises (such as Weekly Reports) must be assigned with great care, and the students guided and motivated to reflect deeply.

It’s not clear how to do this reliably. Epistemological self-reflection was measurable in the 2000-2001 FEH physics course, but not in the same course the following year (or at least to the same extent or with the same meaning). These results could serve as a starting point for experimenting with different ways of implementing Weekly Reports, with the goals of identifying more of the parameters that affect reflection and of finding the method most efficient at eliciting the desired kind of reflection. Then, uniform implementation and grading of reports could be used in studies that compare student reflection across different courses and populations, thereby extending the model.

This brings up another class of important questions related to the universality of the complete model. Do students’ epistemological beliefs (including those expressed in reflection-on-learning activities) differ across different populations and physics content domains? If so, how? How do they differ in diverse instructional environments? Must a course have an explicit epistemological focus in order for students to be able to reflect meaningfully on how physics knowledge is constructed? The first of these questions is
being explored in a study in which at-risk students (very different from honors engineering majors) in an ISLE university physics course were assigned Weekly Reports. Preliminary results suggest that the coding scheme described in this dissertation is effective at characterizing students’ reflection, but that students in this class focused almost exclusively on unfavorable ways of learning. More research is needed to explore this question in depth, and to begin to answer other questions about when and how different physics students reflect on their learning. In addition, one would like to determine how a student could be moved towards “more favorable” reflection in the context of a physics course. Similarly, how can we find out which instructional practices reduce students into “unfavorable” epistemologies?

The question of whether students’ epistemological self-reflection can change over time is as yet unanswered. This dissertation has shown that such changes cannot be precisely measured in the context of Weekly Reports over a period of two quarters (at least for these FEH students). Are changes perceptible in other populations or in different kinds of courses? Is epistemological development measurable only over much longer time frames? What is the best way to measure epistemological beliefs over a long period of time, in which students take a number of different kinds of physics courses with different content, instructors, and instructional approaches? We stand a better chance of improving students’ epistemological thinking if we understand the circumstances through which it can be improved.

7.4.2 The connection with conceptual learning

In this dissertation, a strong relationship between kinds of epistemological self-reflection and gains on conceptual physics tests was discovered in a group of honors engineering students taking a specialized course in introductory physics. The most obvious questions that come to mind are again about the model’s universality: Could this
relationship exist in other populations? Does it exist in different kinds of physics classes? Under what conditions can successful predictions of conceptual learning gains be made from measurements of epistemological self-reflection? What if different measures of conceptual understanding are used? What if epistemological beliefs are measured in some context other than Weekly Reports? Would the amount of epistemological self-reflection make a difference in any of these other situations? Are each of the different kinds of epistemological self-reflection more or less correlated to conceptual learning in these other situations? Only research in many different contexts can determine how consistent this relationship is across boundaries of population, instructional style, and measurement methods.

The connection between epistemology and conceptual understanding brings up another question: Do epistemological beliefs relate to other aspects of learning physics, such as mathematical ability, qualitative and quantitative problem-solving ability, choice of learning strategy, etc.? Studies have suggested that epistemological beliefs of pre-college students are related to their learning goals, motivation, and study strategy choices in the context of learning science, but no such research exists on such connections in physics classes.

Answers to all of these questions will help in answering a more important question: What are the specific mechanisms that mediate the connection between epistemological beliefs and conceptual learning? Are they connected only by way of learning strategy choice, or is there some other form of connection? Some preliminary evidence presented by Lising suggests that certain unfavorable epistemological beliefs can hinder a student’s construction of concepts. Much more research involving students engaged in the learning process is needed to explore the connection with depth.
Understanding all of these issues will help us develop more complete theories of epistemological beliefs, and ultimately improve the conceptual and epistemological knowledge of all students.
ENDNOTES FOR CHAPTER 7


6 Eugenia Etkina, personal communication.

7 Perry’s study of changes in students’ epistemologies followed each student for four years; see W. G. Perry, *Forms of intellectual and ethical development in the college years: A scheme* (Holt, Rinehart and Winston, New York, 1970).


APPENDIX A

EXAMPLES OF WEEKLY REPORTS FROM 2000-2001

These five reports are from Week 43:

1. What did you learn in lab this week?
   In lab this week we learned how to use our knowledge of projectile motion in a lab setting.

   How did you learn it?
   Our main objective was getting a micro machines car to go from a track jump and land in a target. We had to figure out the distance to place the target so that the car would land in it.

2. What did you learn in lecture and recitation this week?
   In lecture this week we learned more about the problem solving strategy and how to apply Newton's second law of motion to circular motion.

   How did you learn it?
   [Instructor A] showed many different demonstrations and experiments that we observed. We figured out the equation for the gravitational force that an object exerts on another object when one has a radius (such as the earth). We also learned the gravitational
constant. [Instructor A] reinforced our knowledge by giving us multiple story problems to work on. We just began to touch on work and potential energy, but that is for next week's report.

**What questions remained unclear?**

How did they know (in Newton's day) that the distance from the earth to the moon was $(3.8)(10^8)$ m? I am also confused on how we come up with equations. It is easy for me to just accept them. (such as the equation for gravitational force)

**If you were the professor, what questions would you ask to determine if your students understood the material?**

A string 1 m long breaks when its tension is 100 N. What is the greatest speed at which it can be used to whirl a 1 kg?

---------------------------------

1. **What did you learn in lab this week?**

We learned how to decompose motion into two independent components in order to analyze projectile motion.

**How did you learn it?**

We accomplished this by constructing a hot wheel track with ramp so that a car was launched and landed as a projectile. We timed how long the car was in the air and used the distance traveled to find horizontal velocity. Then we used the time traveled and gravity to find the vertical velocity. Then we used trig to find the angle. Then we tested that angle with the angle we got from straight distance trig, and they coincided within a reasonable
error. Then using a similar method for a straight track and a car that drives off the edge of the table we determined the distance a catcher need to be to catch the car. Our experiment worked on the first time and it proved that our method was in fact correct.

2. What did you learn in lecture and recitation this week?
(1) We found that the radial a was equal to the velocity squared over the time. (2) Then we learned a process to solve circular motion problems. (3) Then as another branched of circular motion we found that the gravitational force that an object of mass M exerts on another object of mass m with a center to center distance of R to be this equation: F=(GMm)/(R^2), where G=6.7*10^-11.

How did you learn it?
We learned (1) by creating a vector diagram of v around a circle and used the equation of a=delta v / delta t to find that a is proportional to v^2. Then we found that when velocity and the angle was constant and the radius was increased. This showed that a was also proportional to the inverse of R. So together we developed the equation a=v^2/r. For (2) we reenforced and checked the quality of the strategy by doing ALPS problem III-4. We drew a free body diagram with vectors to find the radial F. Then we applied a component of Newton’s 2nd Law to find a radial, which is in the direction of the F radial vector found. We proved (3) by finding the radial a of a satellite with R distance from the earth with a radius of Re and period of T. Then we derived that F gravity = (mg)/3600 from Fg=ma(radial). From there we found that ma(radial)=(GMm)/R^2. Then we did problem CD4 to reinforce this concept.

What questions remained unclear?
Nothing remains unclear.

**If you were the professor, what questions would you ask to determine if your students understood the material?**

A car with the cruise control set at 20mph is traveling on a circular track with a radius of 250ft and the car weighs 1000 pound. At what angle are the hanging dice in the car hanging? Does this seem feasible, if not why?

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1. **What did you learn in lab this week?**

In lab this week, I learned how to accurately measure the motion of a projectile. Also, along with this, I learned how to accurately predict, using physics formulas in two independent dimensions, where a projectile would land when released with a velocity at an angle.

**How did you learn it?**

Our group designed a track which allowed a car to accelerate and then jump off a 30 degree ramp. We then calculated the average velocity of the car by timing it, and found its motion in two dimensions to find the precise landing location of the car on the target, which was a box raised above the ground.

2. **What did you learn in lecture and recitation this week?**
This week in lectures we learned more about the basics of circular motion. The idea of using Newton's second law coupled with the equation for radial acceleration was once again reinforced. Most of the week, however, was dedicated to a new topic: Newton's Law of Gravitation. This law states that two bodies in space exert a force on each other defined by a certain equation. This new topic, together with the ideas of circular motion, is very important to such things as finding orbits and orbital speed of satellites.

**How did you learn it?**

Instructor B once again reinforced the idea of radial acceleration by vertically spinning a rope with a bucket attached filled with water. Surprisingly, the water stayed up against the bottom of the bucket, reinforcing the idea that there is a force from the center of a circular path that is exerted on the object that is being rotated.

**What questions remained unclear?**

Truthfully, I am not clear on much learned this week. I do not feel that the book and ALPS problems reflected the class lessons much at all. I don't know if i was the only one who thought this way, but i hope that in the future that the class lessons become more clear.

**If you were the professor, what questions would you ask to determine if your students understood the material?**

If a satellite is rotating the earth 400 km above the surface, how many orbits would it make in 24 hours?
1. **What did you learn in lab this week?**

   We learned how to decompose motion into two independent motions (horizontal and vertical), and we learned how to analyze projectile motion which can also be divided up into horizontal and vertical components of motion.

**How did you learn it?**

   In part one of the lab we calculated the velocities of a car jumping off a ramp in both the x and y directions in order to determine the angle of the ramp. In part two of the lab, we knew the time it took for the car to fall to the ground and used that to determine the total x displacement in order to decide where to put a box to catch the car when it flew off the table.

2. **What did you learn in lecture and recitation this week?**

   1. The acceleration of an object attached to a string moving in circular motion is greatest at the bottom of the circle. 2. We learned how to add velocity vectors to find the acceleration of an object moving in circular motion. 3. Acceleration is proportional to the velocity squared over the radius (a=v²/r) for an object moving in circular motion. 4. Newton's second law (f=ma) also applies to circular motion so we can evaluate problems with forces acting in multiple directions. 5. The gravitational force an object of one mass exerts on an object of another mass separated by a certain distance is found by the formula F=GmM/r² where G is the constant 6.7x10¹¹ Nm²/kg².

**How did you learn it?**

   1. [Instructor A] taught us the method of adding velocity vectors to find acceleration. The acceleration vector is greatest at the bottom of the circle. 2. [Instructor A] showed us the
method to add vectors. Draw a vector tangent to the circle before and after the point you are trying to find the acceleration for, then put the tails together and draw a new vector from the first velocity vector to the second one. This is the change in velocity and the acceleration. 3. This property was derived in lecture by using a drawing of two circles of different sizes. When the acceleration is examined, the relationship between the velocity of the two objects and the radius of the two circles is equal. We solved problems in lecture and recitation with different examples of objects traveling around a circular path. 4. We practiced applying Newton's second law in component form. We were taught to create a radial and tangential axis to the motion in order to evaluate problems like the loop-the-loop example. We also worked on a problem about the moon in class where we used the period of the moon around the earth and the radius of the moon to determine the centripetal acceleration of the moon. 5. [Instructor A] had a very confusing lecture on this topic, but I remember how to apply the formula from physics in high school. In lecture we applied this formula to a problem to determine the force of the moon on the earth. We also did context rich problems to practice.

**What questions remained unclear?**

I didn't really have any particular questions this week, but I do have a hard time understanding [Instructor A]'s point of the lectures sometimes. Perhaps he could define the topics before we started working on them rather than expecting us to be able to predict what he is trying to talk about.

**If you were the professor, what questions would you ask to determine if your students understood the material?**
1. I would have them draw velocity vectors and add them to find the acceleration of an object in circular motion. (picture needed) 2. If an object is traveling with a velocity of 5 m/s down a ramp, how far away from the table will it land if the table is 2 meters above the ground. 3. A 60 kg person is riding a 10 kg bike at 10 m/s around a circle with a radius of 50 m. What is the force the road exerts on the bike?

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1. What did you learn in lab this week?

In lab we learned about projectile motion, and how motion can be separated into two separate motions, vertical and horizontal. In projectile motion, an object has a constant horizontal velocity, while it accelerates or decelerates vertically with an acceleration equal to that of gravity. In the lab we were able to use these two concepts to determine the angle with which object left the ground, and the distance an object could travel when launched at a certain angle.

How did you learn it?

For the first experiment we found the angle of a ramp off which a car was launched. We accomplished this by first measuring the length of two sides and utilizing them in a trigonometric identity to find the actual angle of the ramp. Then, utilizing equations specific to either the vertical or horizontal motion of the car, we found the velocity of the car in the horizontal and vertical directions, and applied those to the tangent trig. equation. This answer resulted in an angle that was only .2 degrees off. This proved that the one motion of the car does indeed have two independent motions within it. These motions, when added together will yield the same motion as the original one. The second experiment involved a
toy car sliding down a ramp and off the lab table into a box. To find the distance the box
had to be placed from the table, the horizontal and vertical motion equations were agian
utilized. After finding the angle of the incline by applying the height and length of the
incline to the inverse sine equaiton, the acceleration of the car down the ramp was first
variable to be found, by comparing it to gravity as the vertical force and the angle of the
incline. This was then used to find the velocity of the car at the bottom of the incline. This
value was then used as the horizontal velocity of the car once it rolled off of the table. The
time of flight then had to be found to determine the horizontal distane the car traveled. To
do this, the vertical motion was used. The original velocity in the vertical direction was
zero, the accleration equal to g, and the height from the table to the box was measured. The
time was then found and applied to the horizontal motion, which then yeilded a distance.
When tested, this answer was correct.

2. What did you learn in lecture and recitation this week?

In class we learned about uniform circular motion. Uniform circular motion involves a
constant speed of the object. The velocity of the object is changing, however, because
though its magnitude remains constant, its direction is constantly changing. Since the
object's velocity is changing, it also accelerates. The direction of acceleration is towards the
center. Circular motion is caused by an initial velocity and a force towards the center of the
circle. There are two types of acceleration involved in circular motion, radial and tangential.
Radial involves the velocity of the object and the radius of the circle, while tangential
velocity is the speed divided by time.

How did you learn it?
To prove the net force on an object in circular motion, and therefore the acceleration, point towards the center of the circle, a vector diagram was used. On a circle, when a velocity vector from a point after the point being analyzed on the circle is subtracted from a point before the analyzed point, the result is the change in velocity, which is the acceleration. Since the velocity vectors are equal in magnitude and opposite in direction, they will point towards the circle's center. To demonstrate these principles, two experiments occurred during class. The first involved a bowling ball. If the ball was rolled and then tapped with a force pointing towards the center of a circle drawn on the table, the ball followed a circular path, which shows that circular motion is the result of an initial velocity and then a force, which indicates an acceleration, towards the center. The second experiment involved a bucket of water swinging in a vertical circle. The water never left the bucket, though, even when inverted. The reason for this is the bucket was moving in a circular motion while the water was moving in a projectile motion. Since the bucket was moving fast enough, it was able to constantly catch the water before it had the opportunity to fall. If the bucket had been moving slower, the water would have fallen out because the acceleration of the bucket towards the center would not have been fast enough for the bucket to catch the water, accelerating down at the force of gravity.

**What questions remained unclear?**

I'm still a little confused about the concept of an object orbiting the earth while gravity is still acting on it. How can the horizontal velocity of the object counteract the force of gravity when we just learned that the horizontal and the vertical force of an object are independent of each other?
If you were the professor, what questions would you ask to determine if your students understood the material?

What is the radial and tangential tension in a 2 meter string attached to a 2 kg ball when the ball is in a vertical circle and has a velocity of 22 m/s when at an angle of 0 degrees? What is the minimum speed a rollercoaster car can travel through a loop to ensure it, and its passengers, won't fall? The car and people weigh 40 kg, and the radius of the circle is 6 meters.

The next five reports are from Week 47. There was no lab that week, so the students did not answer Question 1:

2. What did you learn in lecture and recitation this week?

In lectures, we talked about inelastic and elastic collisions. In an inelastic collision, the total kinetic energy of the system is different before and after the collision. In an elastic collision, the kinetic energy of the system is conserved throughout the reaction. We were given equations like \( v_{1f} = \frac{(m_1-m_2)}{(m_1+m_2)}v_{1o} \). And \( v_{2f} = \frac{(2 \times m_1)}{(m_1+m_2)}v_{1o} \). These equations show that the velocities of two objects, if mass 2 is greater than mass 1. We also learned about statics. On an extended rigid object, the location of where the force is being applied needs to be known. We also learned that every object has a center of mass. This center of mass hangs directly below the pivot point. When the force goes through the center of the mass, no rotation occurs, but if the force goes astray, rotation will occur. The force that the object turns at is called the torque. The torque is equal to the force times the distance times the sin of the angle.
How did you learn it?

We learned about elastic and inelastic collisions through the lectures of [Instructor B]. We learned by [Instructor B] showing us about these type of collisions via the work-energy equation. In an elastic collision the work-energy can be set up using kinetic energy. I learned about how these concepts relate to circular motion through practicing problems. We did problems that involved a swinging vine and the max tension the vine could support. We used the conservation of momentum to show the relationships before the collision and after the collision. We learned about statics only in lecture last week. [Instructor B] showed that the center of mass hangs directly below the pivot point. He hung an object on a projection and hung a string from the projection also. Where the string runs across is where the center of mass is located. He also demonstrated how an object rotates when the force does not go through the center of mass.

What questions remained unclear?

When a force to an object and the force does not pass through the center of mass, the object still moves forward. Therefore, some of the force is used for the torque and some is used to move the object forward. How does one go about determining how much force goes to what?

If you were the professor, what questions would you ask to determine if your students understood the material?

A question about the torque could be asked. The distance would be given as would the angle and the angular acceleration provided by the torque would need to be found. Also any questions involving the work-energy equations could be given. I’m sure on the
midterm, we’ll see questions involving the ballistic pendulum which was an example in class.

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2. **What did you learn in lecture and recitation this week?**

We learned about conservation of momentum. We learned of special cases of collisions such as elastic, inelastic and partially elastic. We learned about the concept of torque used to turn rigid extended objects.

**How did you learn it?**

We did George and Ape problem on board. George swung down and grabbed Ape. Unfortunately, we found out he was not going fast enough for them to make it to safety. We observed different types on the air track. We observed how the door turned when pushed from certain angles and distances from pivot point.

**What questions remained unclear?**

A little confused on torque but questions were answered on Monday in lecture.

**If you were the professor, what questions would you ask to determine if your students understood the material?**

Ones like George and Ape. Given initial condition and masses and must figure out if situation is possible.
2. What did you learn in lecture and recitation this week?

We reviewed multi-part problems using work-energy and momentum equations, and used work-energy to learn about elastic collisions. Also, we explored the conservation of momentum depending on the system selected.

How did you learn it?

First, we did problems such as the one involving George of the jungle where he needed to swing down on a vine, grab a monkey, and swing up onto a ledge. We used energy to find George's velocity right before he hits the monkey, and then conservation of momentum to find the velocity after the collision. Finally, we used energy again to analyze the upswing to determine the height of the swing, and whether or not they will make it onto the ledge, which, by the way, they did not. Next, we applied energy equations to a collision. The initial kinetic energy of both is equal to the final kinetic energy of both, so if one object is not moving, \( .5m_1v_1^2 = .5m_1v_1'^2 + .5m_2v_2'^2 \). Thus, if the masses of the two objects are equal, one will stop when it hits the other. We observed this with balls of equal mass suspended by strings, and found it to be true. We also tested this equation with balls of different masses, a small ball and a bowling ball, and found that the ball of larger mass influenced the other ball more, and was less influenced when it hit the other ball. A special case of elastic collisions is a head on collision, in which case \( m_1v_1 = m_1v_1 + m_2v_2 \). Last, we observed situations with a block on a ramp. From these we learned that momentum is conserved universally, but not always in a particular system.

What questions remained unclear?
How do you determine whether a collision will be elastic or inelastic? How do you deal with partially elastic collisions?

If you were the professor, what questions would you ask to determine if your students understood the material?
Is energy conserved in an elastic collision? If two .2kg bouncy balls collide in mid-air, both traveling at 2 m/s, what is the final velocity of each ball? If an 80kg stuntwoman is launched out of a cannon at a 45 degree angle by a spring with a constant k=31360 that is compressed 1m, how far away should the net be placed to avoid hospitalization?

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2. What did you learn in lecture and recitation this week?
This week in recitation we began to learn about the new area of rotational motion and statics. Rigid extended objects are a main focus of this. These objects have a special point called a center of mass, which always hangs below a pivot point. If a force is applied to a line of action, which is basically a line passing through the center of mass, no rotation will occur. However, if a force is applied in another direction than a line of action, rotation will occur. A Torque must be applied to the object to cause rotation to start. Torque is defined as the force applied to the object times the distance from the pivot point to the perpendicular on the line of force.

How did you learn it?
[I instructor B] used a few demonstrations to demonstrate rotational motion. First, he used a teeter-totter type setup to show how torque can be used to steady the setup. On one side he
placed a 5 kg mass, 50 cm from the center. He then told the class to figure out where 2-2 kg masses were to be placed on the other side of the pivot point. Using what had been taught about torque it was figured that one mass should be placed 50 cm away, and another 75 cm away. The extra distance on the second would equal out the torque, therefore balancing the system.

What questions remained unclear?

How do you determine which (momentum, force, or work-energy) to use in solving a system?

If you were the professor, what questions would you ask to determine if your students understood the material?

If a force of 40 newtons is applied to a door at a 45 degree angle, what will be the torque?

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2. What did you learn in lecture and recitation this week?

1. Kinetic energy is conserved in an elastic collision. 2. Momentum is conserved in an isolated system. 3. We learned the results of several special cases of elastic collisions.

How did you learn it?

1. We observed an experiment with a ball that bounced demonstrating an elastic collision where energy is conserved and a ball that didn't bounce which showed that energy was somehow transferred. 2. We practiced with problems in lecture on the board and from the book and alps in recitation. We also observed some experiments in lecture to demonstrate
3. We watched a demonstration with an air cart and different masses to see how each situation results. We also tried to figure out some activphysics simulations such as a skier being stopped at the bottom of a hill by a spring and a cart simulation. These helped us practice working multipart problems.

**What questions remained unclear?**

1. Why is it always possible to isolate a system in a certain direction so momentum is conserved? 2. How can we solve problems that aren't fitting into the criteria of the special circumstances defined in class?

**If you were the professor, what questions would you ask to determine if your students understood the material?**

1. If a 20 kg cart collided with another 20 kg cart perfectly elastically and the first cart was initially moving at 5 m/s and the second cart was at rest, what will be the final velocity of the carts? 2. If a child slides down a 10 m high slide and collides with his mom at the bottom, what will be the velocity both are moving at if the mom catches the kid?
APPENDIX B

EXAMPLES OF CODED WEEKLY REPORTS FROM

2000-2001

What follows are all of the Weekly Reports submitted by the high gainer John (Student 12 from Chapter 4), coded with code numbers in the margins. Note that, as with the reports of all students, some of what John writes is not coded, because it does not fit the coding scheme developed in Chapter 3.
1. What did you learn in lab this week?

I learned in lab how the angle of incline affects the acceleration of an object. Not only does it affect the acceleration, but also the velocity. I also learned about human reflexes and our reaction time.

How did you learn it?

We took a matchbox car and an inclined ramp and started the car at the top while starting the timer. The track was exactly 1 meter long and we stopped the timer when the car reached the end of the track. By using the formulas \( D = VT \) and \( D = 1/2AT^2 \) I was able to calculate the average and instantaneous velocities and the acceleration of the car. To calculate our reaction times, we held a meter stick even with the top of our hands and dropped the stick while the other person grasped onto the stick. We then measured the distance in which it took to stop the meter stick and calculated the reaction time using \( D = 1/2(T^2 - 9.8T) \).

2. What did you learn in lecture and recitation this week?

I learned that if a spring is elastic the amount it stretches is proportional to the amount of force applied to it. I also learned the amount of surface area in contact with another surface doesn’t affect the amount of force required to move the object. I also learned that the force that one object applies to another is equal to the force that object applies back to the original object.

How did you learn it?

We took a tension spring and hung an amount of weight from it and measured the distance it stretched. Then we doubled the amount of weight and the stretch distance also doubled. We then hooked a truck with constant velocity to a force scale and hooked the scale to a block and pulled it across the table top, measuring the force. Then we turned the block on its narrow side and pulled it, again measuring the force. The force needed to pull the block remained the same both times. We then had 2 identical carts with force measuring devices attached to the front end of each one. We pushed the carts with equal velocities toward each other and they applied equal forces to each other. Then we gave the one cart a higher velocity than the other and they still applied equal forces to each other.

3. What questions remained unclear?

I have trouble drawing all the forces on diagrams and figuring out the magnitudes of the forces. I still have trouble remembering the formulas.

4. If you were the professor, what questions would you ask to determine if your students understood the material?

A person is pushing a crate to the right at a constant acceleration of \( .5 \) m/s\(^2\). The mass of the crate is 10 kg and assume a frictionless surface. What is the force required? What about with a coefficient of friction of \( .2? \)
Week 41

1. What did you learn in lab this week?

I learned how to create a vertical and horizontal accelerometer from a scale and some string. I also learned that as long as the force remains constant, the acceleration will remain constant. The lab also helped prove Newton's 2nd Law.

How did you learn it?

To create the horizontal accelerometer we took a scale and taped it to the provided car and attached the string to the bottom of the scale. We then hung the string over the end of the table and attached a weight to the end of the string. When we let go of the string the weight applied a force to the car causing it to accelerate. Using the formula $F=MA$ and knowing the mass of the cart and the force applied to the cart, we were able to calculate the acceleration. To create the vertical accelerometer we took a T-stand and hung the scale from it with a 200g weight attached to the bottom of the scale. With the accelerometer placed in the elevator we were able to see the force applied when the elevator accelerated and decelerated. Using the same equation $F=MA$ we can calculate the acceleration since we know the mass to be 200g.

2. What did you learn in lecture and recitation this week?

I learned that while working Newton's 2nd Law you must follow an order of instructions to solve the problem. First, you must choose the system, or the object of interest. Then make a free body diagram of each system. Then apply Newton's 2nd Law in component form, by setting one axis so that the acceleration upon that axis is zero.

How did you learn it?

We took two pulleys and hung a weight on each end of the string and strung the string through the pulleys. One weight was slightly heavier than the other so to create an acceleration. Since we knew the distance and the force of the acceleration we were able to calculate the acceleration and the time it took to fall using the equations $F=MA$ and $Y-Y_0=V_{oy}t+.5AT^2$.

3. What questions remained unclear?

When there are a lot of unknowns and you must just use the letters and then solve and cancel out the unknowns it gets confusing. For example tension was canceled out on the problem I described from lecture.

4. If you were the professor, what questions would you ask to determine if your students understood the material?

A man pushes on a 3kg crate at a 34 degree angle to the horizontal as it slides down a vertical wall at a constant velocity of .3m/s. What force would the man need to apply to stop the crate before it hits the ground 2m below the crate when the coefficient of friction between the crate and the wall is .3?
1. What did you learn in lab this week?
   How to determine the kinetic coefficient of friction. The difference between mass and weight and how it affects an object with a positive velocity once the force is greater than the friction force. I also learned how to predict the greatest amount of weight to be pulled by use of Newton's 2nd Law.

   How did you learn it?
   We took an inclined surface and raised one end until the constant velocity machine spun and had a velocity of 0 m/s. We took the slope of this incline by measuring the rise over run and found the coefficient of kinetic friction by dividing the friction force by the normal force. We then lowered the angle of incline to 14 degrees and using Newton's 2nd Law took the friction force minus the horizontal component of weight and that gave us the amount of weight we could pull. Then we calculated the amount of weight we could pull directly behind the machine by taking the friction force minus the horizontal component of weight times the cosine of 76 degrees to get a mass of 410g.

2. What did you learn in lecture and recitation this week?
   We learned about projectile motion and how the horizontal motion and the vertical motion are independent of each other. By changing the angle of incline you can control the distance or the height of an object at a set velocity.

   How did you learn it?
   We took a cart moving at constant velocity and shot a ball up out of it, only to see the ball fly up and land back in the cart. Then we took a spring loaded ball and shot it straight up noting that it went up 2.6m. We wanted to predict the angle we needed to shoot the ball at to reach a box 4.2m away. So we found the initial vertical velocity using the formula \( V_y = V_{oy} + \frac{g}{2} \) and then used the formula \( X = X_o + V_{ox}T \) to find the angle we needed.

3. What questions remained unclear?
   On Friday in lecture, we went over what I thought was centripetal force, but we were never told what the force acting the swinging ball was. Also, I was wondering when we would be getting the exam grades back and if there is any curving or anything like that.

4. If you were the professor, what questions would you ask to determine if your students understood the material?
   A ball with an initial vertical velocity of 22m/s needs to land in a bucket 11m away. What angle of incline should the ball be shot at to land in the bucket? What is the other angle that would also work to land in the bucket?
1. What did you learn in lab this week?

I learned in lab that the horizontal motion is independent of the vertical motion of an object. Also, I learned how to find the launch angle of an object using known quantities and equations and also be able to predict the distance an object will fly. Additionally, I learned how to analyze the different components of projectile motion.

How did you learn it?
We took a declined ramp attached to a jump at the bottom and launched a toy car. We were able to find the launch angle by measuring the rise over the run of the jump. Then we launched the car and measured the inflight distance, height and time. Using the formula $Y = Y_0 + V_{0y}T + \frac{1}{2}(-10)T^2$ we were able to find the vertical component and using the formula $X = X_0 + V_{0x}T$ to find the horizontal component. Then placing the vectors head to tail and finding the resultant vector and angle of the jump. To figure out the distance an object travels we found the velocity of the object as it left the table. Then knowing the distance to the ground and the constant force of gravity acting on the object we can calculate the distance by using the formula $X = X_0 + V_{0x}T$ where $T$ is the time it takes the object to fall from the table to the ground, or box in our case.

2. What did you learn in lecture and recitation this week?

I learned in lecture that the change in velocity divided by the change in time is equal to the acceleration and that the acceleration of an object is equal to the velocity squared divided by the radius. I also learned how to find the tension and acceleration of a pendulum. Finally, I learned how to find the mass and other unknowns in gravity problems.

How did you learn it?
We took an object moving in a circular path and measured the velocity in two equidistant points A and B from a specified point C. Then we recorded the time at points A and B which leads to the formula $a = (V_a - V_b) / (T_a - T_b)$. Then using the same technique but for twice the velocity we find that $a = (V/a) / r$. To find the tension and acceleration of objects traveling in a circular path we use the sum of the radial forces $= m *$ radial acceleration. We learned that the acceleration always faces toward the center by putting the velocity vectors tail to tail and finding the change in velocity. Using the formula $G((M_1 M_2) / (r^2)) = $ Force of gravity where the two masses are the masses of the planets and objects and $r$ is the radius between the two. $G$ is a gravitational constant that equals $6.7 * 10^{-11}$.

3. What questions remained unclear?

I am still confused about some of the gravity problems. I couldn’t figure out the homework yet, but I hope Monday lecture will help me.

4. If you were the professor, what questions would you ask to determine if your students understood the material?
A 5K/g mass is swinging on a 1m string at a constant velocity of 10m/s. What is the acceleration acting on the object?

Week 44

1. What did you learn in lab this week?
   In lab I learned how to measure physical quantities characterizing circular motion. In addition to that, I also learned to identify what forces provide an object with a centripetal acceleration.

   How did you learn it?
   We took a small toy plane and attached a string to it. Turning the motor on, we threw the helicopter in a circular motion. By measuring the distance from the top of the string to the top of the helicopter while it was in motion, and measuring the length of the string, we were able to find the angle from the horizontal of the helicopter in flight to be 63.8 degrees. We then weighed the helicopter and found the circumference to be 2(π)(38.6cm)=242.5cm. Taking 242.5cm/3.85sec=62.9m/s and then using (2.9)^2/3.86m to find the centripetal acceleration to be 21.8m/ss. Then to find the horizontal force we took .139kg=21.8 to get 3.03N. Then we took 3.03cos(26.2) to get a tension force of 3.38N.
   Then, to further imprint the idea of acceleration, we took a double pulley system with equal masses. Raising one mass to the side and releasing it, we found that the swinging mass will slowly accelerate downward at the bottom of the swing arc, causing the other mass to raise slowly.

2. What did you learn in lecture and recitation this week?
   In lecture I learned the components of conservation of energy and the associated formulas that go along with it. I also learned how to solve problems by using bar charts and substituting in formulas for variables.

   How did you learn it?
   We observed a large mass being dropped on a piece of chalk, crushing it. Then the chalk was dropped on the mass, nothing happened. This showed how gravitational potential energy depends on mass and relative elevation. Then we observed a ball being compressed on a spring and watching the spring shoot the ball up. This displayed the elastic potential energy of a spring. Then by observing a moving car being slowed down, we observed the concept of kinetic energy. We then learned that work is a force acting on an object from outside the system by watching a person fall on a sponge and the work done by the sponge on the person, caused the person to stop. We then were told \[ K=.5MV^2 \] where \( K \) is the kinetic energy and \( Us=.5KX^2 \) where \( Us \) is the elastic potential energy and \( K \) is the spring constant. By using bar charts we learned that the sum of the initial energies of a situation must be equal to the sum of the final energies of the situation since energy is conserved. To find the formula for gravitational problems, we took two large masses, like planets, at distance \( R_i \) and then applied a small force so there is approximately no acceleration to a distance of \( R_f \) from the other mass. We then get
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\[ W_{ext} = (-GM_1M_2)/(R_1) - ((-GM_1M_2)/(R_1)) \text{ and so we also get } U_g = (-GM_1M_2)/K \text{ and } U_g = MGY. \]

3. What questions remained unclear?
Nothing specific at this time. I just need to practice the new material.

4. If you were the professor, what questions would you ask to determine if your students understood the material?
A 10Kg mass is compressed 5m on a spring of constant K. When released, the mass slides up a frictionless incline of 27 degrees to a distance of 150m. What is the spring constant required for this?

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Week 45

1. What did you learn in lab this week?
NO LAB!!!

How did you learn it?
No lab

2. What did you learn in lecture and recitation this week?
In lecture I learned how to work problems using conservation of energy and quantitative bar graphs. I also learned that power in watts = work/time.

How did you learn it?
We solved several problems in lecture, working completely through them. There was an elevator moving upward at 4 m/s, and came to a stop in 4 m. Using the bar graphs, we see that there is kinetic and work initial energies. Once the elevator has stopped, there is only U_g (gravity) acting on the elevator. Then to solve, we simply put in \( 5MV^2 \) for K and FD for work and MGY for U_g. Next, we took two masses connected together with a string, and hung them on a frictionless, massless pulley. We set one mass on the ground, and by knowing the weight difference and the height of the other mass we were able to calculate the velocity of the hanging mass when it reached the ground and the time it took. Using the bar graphs, we see that U_g = U_g + K. Then substitute the formulas and the known quantities into the above equation and you will get velocity. Then using \( V = V_0 + AT \) you get the time. We did several spring problems in lecture too. We had a cart that needed to be shot up a hill to a distance of 50 m. Using the bar graphs, we get U_so = U_g + U_int, then substituting in the equations and the known values we can solve for the spring constant needed when the spring is compressed 10 m. We also did one problem in lecture that was a two part problem. We had to find the projectile motion of an object to get it to land in a box. Then knowing the velocity the object needed, we setup the bar graphs and got U_so = K and then substituted in the equations and known quantities. Then at the end of class, we were told that power = work/time which makes perfect sense, since it takes more energy to move something faster.

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3. What questions remained unclear?
Tension and circular motion still are a little cloudy. Maybe if we worked through a few problems in class it would help. I really learned a lot from Wednesday’s lecture by working through those conservation of energy problems.

4. If you were the professor, what questions would you ask to determine if your students understood the material?
A large AC motor lifts an elevator to the top of a highrise building. The elevator rises a total of 150 m in 24 s. The elevator weighs 1500 kg and can hold up to 2000 kg. What is the smallest horsepower motor that would be needed to lift the elevator fully loaded?

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Week 46

1. What did you learn in lab this week?
In lab, I learned how to identify different kinds of energy and how they transform into one another. I also learned to distinguish between elastic and inelastic collision. Finally, I learned to characterize different types of collisions from the point of view of energy and momentum.

How did you learn it?
We measured the vertical height of the car shot out of the launcher at each of the four settings. Then using the equation $m(9.8)h$ where the mass is .0525 kg and $h$ is the height the car traveled to find the potential spring energy at each setting. Then using energy equations for the car while at the top of the loop we get $U_s = U_g + K$. To find the minimum velocity required to send the car through the loop without falling we use Newton’s 2nd law $F_r = M(V^2/R)$ where the radius is .11 m and $F_r = N - W$ and $N = 0$. Substituting in the known information and the known velocity we solve for the minimum $U_s$ required to send the car through the loop without falling.

2. What did you learn in lecture and recitation this week?
I learned what an impulse is and about momentum conservation. I also learned that momentum along the x direction is conserved and that momentum along the y direction is conserved.

How did you learn it?
We examined a collision between a 60 kg truck moving at 36 m/s and a wall, where the truck collapsed 1 m. We found the time using $X-X_o = .5(V_o + V)T$ to be .055 s and substituting the known quantities into the impulse momentum equation $F(T-T_o) = MV - MV_o$ to get a force of 39,273 N that was exerted on the person in the truck by the seatbelt. We then took two masses sliding in perpendicular directions towards each other. To find the velocity in the x direction we use $M_1V_{1x} + M_2V_{2x} = (M_1 + M_2)V_x$ then used the same equation but with the y direction velocities to find the vertical velocity. Then put the vectors head to tail to find the resultant velocity and angle. We then used our
knowledge of energy, momentum, and projectile motion to solve multi-part problems by
breaking the problem down into small manageable steps using the equations for the type of
problem that particular step was.

3. What questions remained unclear?
Is there ever really a perfectly elastic collision?

4. If you were the professor, what questions would you ask to determine if your
students understood the material?
A 50 kg person slides halfway down a 75 m hill at an angle of 30 degrees above the
horizontal then grabs onto a stationary 100 kg cart. What is the final velocity of the
cart/man at the bottom of the hill?

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Week 47

1. What did you learn in lab this week?
no lab

How did you learn it?
no lab

2. What did you learn in lecture and recitation this week?
I learned how to solve multiple part problems by breaking them into small individual
problems and applying work energy equations. I also learned about elastic collisions.

How did you learn it?
We had an object hanging from a string and was released in a circular motion. The object
then collided and combined with another object at the bottom of the swing arc, and we
were to find the height that the two objects would swing up to. First, we broke the
problem into 3 smaller problems. The first problem was Ug=K. The second problem was
M1Vi=(M1+M2)Vf. Finally, we take K=Ug. To solve these equations, simply substitute
in the known amounts, and solve for the one unknown in each equation. For elastic
collisions we were given the formula K1o+K2o=K1+K2. We then had 2 balls with a
spring on each one, collide and were able to find the distance that the spring
compressed. Using M1Vi=(M1+M2)Vf and then K=Us and knowing the masses and the
spring constant.

3. What questions remained unclear?
Finding the correct orientation for the axes on a Newton's 2nd problem still confuses me.
Will the final contain the same principles covered in the midterms, or will you sneak new
things in there?

4. If you were the professor, what questions would you ask to determine if your
students understood the material?
Tarzan is in a 50m tree with a 50m rope. There is a spring with a constant of 500N/m positioned on the ground to stop him. Attached to the front of the spring though, is a 100k wall. If Tarzan weighs 200k, how far will the spring compress? Assume everything is frictionless and the spring is massless.

Week 1

1. What did you learn in lab this week?

no lab

How did you learn it?

no lab

2. What did you learn in lecture and recitation this week?

3. In recitation I learned that similar charges repel each other and opposite charges attract each other. We worked several ALPS problems to learn this. It was in lecture that I learned the relationship between distance and strength of the charge and how those two factors affect the strength of the attraction or the repellant.

How did you learn it?

We saw [Instructor C] use foam tubes to demonstrate how there are two charges. These charges either attract or repel each other depending on their combination. Later, we learned that opposite charges will attract each other and like charges repel each other. Using the foam pipes again, we learned that the distance the charges are from each other affects the strength of the reaction and that the amount of charge also affects the strength of the reaction. Finally, we derived the equation \( F = \frac{KQ_1Q_2}{R^2} \) where \( K = 8.989 \) and \( R = \text{distance} \).

3. What questions remained unclear?

Where did the constant \( K = 9.989 \) come from?

4. If you were the professor, what questions would you ask to determine if your students understood the material?

If a charged object of strength -3 is 2cm to the right from a charged object of strength -2 and a third object of strength +5 is 2cm to the left of the middle object, what is the direction of the net force on the middle object?
1. What did you learn in lab this week?

I learned how to test and apply the concepts of charging and discharging and the relationships involved in electrostatic interactions.

How did you learn it?

First, we took a piece of tape that had been pulled off the desk and noted how it reacted with multiple materials rubbed by different types of fur. After noting all the combinations and reactions, we predicted that glass is always positively charged when rubbed so we were able to tell how the other objects were charged based on there reaction to the glass. Then using Coulomb's Law we were able to estimate the charge from a piece of tape by measuring the angle between two repelling pieces and using work-energy equations.

Finally, we found that plastic saran wrap will remove a charge from objects.

2. What did you learn in lecture and recitation this week?

We learned applications of Coulomb's Law to solving problems. We also learned about potential energy and how to solve it qualitatively. Finally, we were given a formula to solve dealing with potential energy.

How did you learn it?

We watched a foam tube that was rubbed with fur repel another tube that was rubbed with the same fur. Then we saw that foam rubbed with another type of fur attracted the other foam pipe rubbed with the original fur. We noticed that distance, the amount of charge, and time all affected the strength of the reaction. The same reaction was witnessed with a pendulum system where we were able to take the gravitational potential energy and Coulomb's Law to solve for the charge. Finally, we derived an equation to solve for potential energy between two point charges.

3. What questions remained unclear?

In the homework the last several problems were incredibly hard. I, along with every other student I talked to had no idea how to solve the problems because we had not learned anything about different accelerations and momentums yet.

4. If you were the professor, what questions would you ask to determine if your students understood the material?

Two positive charges of equal strength are placed 1m apart. Then they are moved apart another 1m. Does the initial or final situation have more potential energy?
Week 3

1. What did you learn in lab this week?

No lab

How did you learn it?

No lab

2. What did you learn in lecture and recitation this week?

We learned more about electric potential. We also learned the definition and relationship to the electric field.

How did you learn it?

I learned that the electric field points away from a positive charge and points toward a negative charge by examples up on the board. By drawing a positive center charge with a small negative charge with force pointing towards the center positive charge and electric field pointing away from and then drawing a small positive charge with force pointing away from the center and electric field pointing away from the center. Then, to find the total charge of a line charge and a point charge, we learned that we must use the integral. By taking the total charge for infinitely small sections of the line and adding them up, we are able to calculate the total charge of the whole line and point system. The whole lambda thing confuses me so I can't describe in detail the process, but you must add up the total electric field in the x and y directions.

3. What questions remained unclear?

The formula we received Friday really confused me. Also, if we do ask questions in this section, but our reports from 3 weeks ago still aren't graded, how will we really ever get an answer?? I do not mean to be critical, just making an observation.

4. If you were the professor, what questions would you ask to determine if your students understood the material?

I really do not know the material from this week but I'll try. Two like charges are five meters apart. One positive charge is .00005C and the other charge is .01C. If a cart of negative charge is placed 30cm from the smaller charge, what is the acceleration and direction of the cart? The cart weighs 10kg and has a negative charge of .00005C. Assume frictionless cart.

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Week 4

1. What did you learn in lab this week?

How to describe physical phenomena using the electric field.

How did you learn it?

We took two 20cm pieces of tape and help them close together. We then measured the deflection and the mass of the tape pieces. Using \( mg = kqQ(\pi) \) we were able to calculate the charge per area of the tape. Then taking the known charge and placing it in the formula \( E = kq(\pi) \) we found the E field of a piece of tape. With the E field, we were able to predict how the tape would react to other charged objects by using \( qE \).

2. What did you learn in lecture and recitation this week?

We learned how to take the integral of a point charge and a line charge. We also learned how to find the electric field from a ring charge by taking the integral. Finally, we were briefly introduced to what I think is induction, but we haven't learned the term yet.

How did you learn it?

In lecture, we saw the electric field of a line charge derived out on the board. We wrote \( dE \) in terms of \( dx \) and integrated it along the length of the line in the x direction and y direction. So the general equation we got was \( E_x = \frac{k(\lambda)}{2}x(\pi) \) and \( E_y = \frac{k(\lambda)}{2}y(\pi) \). The x direction will cancel assuming the charge is symmetry.

We then derived the electric field for a ring charge using the integral from the interval 0 to 2\( \pi \). Here the y direction cancels assuming there is symmetry again and we get the equation \( E = \frac{kQD}{(A^2 + D^2)^{3/2}} \). Finally, we observed that a charged metal rod will repel a neutral piece of foam, while a wood rod would not. Again, we observed that a metal can or a plastic bottle was attracted to both a positively and a negatively charged metal rod. In recitation, we worked on a handout that dealt with finding the electric field of a ring charge at point P. We then answered several conceptual questions about the first problem.

3. What questions remained unclear?

The observation we made on Friday with the neutral objects interacting with charged objects, is that induction?

4. If you were the professor, what questions would you ask to determine if your students understood the material?

Find the force on a charge placed in the middle of two line charges. This demonstrates the concept of an electric field, but without the complicity of an integral.
Week 5

1. What did you learn in lab this week?

   I learned how to apply the concept of electric field to solve practical problems. In addition, I learned the difference between conductors and dielectrics.

   How did you learn it?

   We predicted what would happen if we placed a charged object near an electroscope. We then proved our predictions by performing the experiment. We found that conductors, such as metal, had no effect on the electroscope which we predicted to be a result of induction where the electrons move freely. However, when a charged dielectric, or plastics, was placed near the electroscope the read inside was repelled. To solve practical problems, we devised a method to remove the charge from an object. We touched two objects of opposite and equal magnitude charge together and the charge on both of them neutralized. We proved there was no charge left by holding the objects near the electroscope and to each other and no interactions occurred.

2. What did you learn in lecture and recitation this week?

   I learned some properties of conductors. I learned some fundamental aspects of a circuit. We discussed some concepts such as current, resistance, and voltage. Using Ohm's Law $V=IR$ we learned how to calculate the voltage, resistance, and current from various circuits.

   How did you learn it?

   In lecture we observed that a metal bucket with a charge on it had no interactions with objects on the inside of the bucket, while interactions did occur on the outside. This proved that electrons are free to move around. We then discussed Ohm's Law and how $R=\text{length}/\text{area}$. To prove this, we observed the resistance in one wire and compared it to a wire with four times the cross-sectional area and another wire of half the length. We were then given more information about $V=IR$ where it refers to one specific resistor and current and the voltage drop. Also, if current goes over a power source the voltage goes up, while if the current goes over a resistor the voltage goes down. We also observed numerous circuits on the board and worked through calculating the currents and resistances. Finally, we observed how the resistance of a wire transforms the voltage into heat by lighting a piece of paper on fire. In recitation we went over a worksheet with several circuits drawn on it. From the given information, we calculated the resistances, currents, and voltages throughout each circuit.

3. What questions remained unclear?
several problems involving capacitors in parallel and in series. By applying the laws and equations we learned in lecture, we were able to work through most of the problems.

3. What questions remained unclear?

When a circuit has parallel and series resistances combined it gets confusing. But, the loop rule really helps me. I really like working through a couple of problems in recitation, seeing someone work completely through a "textbook" problem is the best way to learn.

4. If you were the professor, what questions would you ask to determine if your students understood the material?

Setup a small circuit with several known resistances or voltages and let us solve for the unknown. To get even trickier you could combine resistances and capacitors in the same circuit.

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Week 7

1. What did you learn in lab this week?

I learned how to apply the concepts of electric circuits and practice the skill of design.

How did you learn it?

We used 12V which could come from a typical car battery, and designed a circuit with a piece of Nichrome as a heater. First, we found the amount of work needed to raise the temperature of 250mL of water 35 degrees celsius. Then knowing we had 8 amps and 12 volts to work with, we solved for the watts and time. Then knowing the total amount of resistance that was needed we used the resistivity formula to find the length of Nichrome we needed.

2. What did you learn in lecture and recitation this week?

The relationship between a capacitor's charging and discharging times and the time constant. I learned the properties of magnets and magnetic fields. Finally, I learned the principle of maximum voltage or breakdown.

How did you learn it?

By plotting charge versus time and current versus time and seeing that the resistance x capacitance is the time constant and is equal to approximately 63% of the the total charge time of the capacitor. We were then given equations to find the charge or current for any time 

t during the charge or discharge of the capacitor. We then saw how the magnetic field flows from the North pole to the South pole. We also learned that magnets and static...
I am still confused about how a parallel circuit affects the voltage and current so differently than a series circuit.

4. If you were the professor, what questions would you ask to determine if your students understood the material?

Give us a simple circuit with some resistors placed throughout it. Then have us solve for the unknowns in the circuit.

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Week 6

1. What did you learn in lab this week?

How to analyze DC circuits.

How did you learn it?

We were given a box with a power source with an "internal resistance" and we had to find this resistance. By using the loop rule and finding the current through the circuit with no resistance and then solving for the EMF. They by substituting that EMF into another equation from a circuit with a known resistance and current we were able to find the "internal resistance" and then find the EMF. We did the same procedure for the second box. For the second part of the lab, we were to draw a diagram of a circuit in which we could not see the wires, but only the lights that they connected. By flipping the switches and viewing the light bulbs' brightness we were able to conclude that half the circuit was in series, while the other half was in parallel.

2. What did you learn in lecture and recitation this week?

I learned about resistive dissipation. I also learned about capacitors and capacitance.

How did you learn it?

Using two pieces of wire with different resistances we witnessed a piece of paper catch on fire. This showed how the energy is changed into heat. We set up numerous circuits involving capacitors and measured the voltages across the capacitors. We showed how the equation Q=CV where Q is the charge and C is the capacitance of the capacitor and V is the voltage is true by using an oscilloscope to see how as the capacitance increases, the voltage drops. Then, to prove the equation V=ED where E is the electric field and D is the distance we set up an electroscope to two large plates. We measured the voltage at a certain distance then we moved the plates farther apart and saw that the voltage increased. We then saw that capacitors in series have less capacitance then if they were individual. And if they were in parallel then the capacitance adds. In recitation, we did
charge don't effect one another and that magnets always have a North and South poles. We also learned the hand rule to apply the direction of force applied to a molecule in a magnetic field. The molecule's path will be circular because the force is always perpendicular to the velocity and the period is dependent upon the magnetic field and not the velocity. Finally, I learned about the breakdown voltage of air which is when the voltage becomes strong enough to pull the electrons through the air.

3. What questions remained unclear?

The $F = QVxB$ concept is still confusing. What does "cross" mean and how does it work?

4. If you were the professor, what questions would you ask to determine if your students understood the material?

Give us some examples of a molecule with velocity and a magnetic field and we are to find the direction of the force.

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Week 8

1. What did you learn in lab this week?

I learned how to apply the concept of magnetic field to practical problems. Additionally, I learned how to determine the poles of magnets and how to construct a simple DC motor.

How did you learn it?

By using a wire with a current running through it and by holding a magnet close to the wire, we were able to determine the poles. Using the right hand rule with our knowledge of the direction of the force and current, we were able to solve for the direction of the B field. And since the B field flows from the N pole to the S pole we were able to tell which pole was which.

2. What did you learn in lecture and recitation this week?

I learned about the B field of a straight or bent wire and a ring of wire. Finally, I learned about solenoids and their B fields.

How did you learn it?

We were shown a demonstration with two parallel wires that were attracted when the current was going the same direction and repelled when the current was in opposite directions. Each wire creates a B field which in turn acts on the other wire, but not its self. With the current going the same direction, the resultant force is inward on both wires, but with the current in opposite directions the force is outward on each wire using

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the right hand rule. For a ring of current, we found by taking the integral of dB we could find the resultant B field at a point on the center axis. The force cancels in the perpendicular direction but is equal to $B = \mu_0 I R R / (2(\pi R + \pi Z)^2)$ in the parallel direction. Finally, for a solenoid we found the B field to be uniform inside the coils and independent of the area resulting in $B = \mu_0 I N / L$ where $N$ is the number of coils and $L$ is the length of the solenoid.

3. What questions remained unclear?

When using "cross" or "X" how do we know whether to use the cos or sin?

4. If you were the professor, what questions would you ask to determine if your students understood the material?

Give us a solenoid with a known current and number of coils and length and have us find the B field.

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Week 9

1. What did you learn in lab this week?

I learned how to apply the concepts of electric and magnetic field to a problem.

How did you learn it?

By using $1/2 M v^2 = qV$ and plugging in the known information of an electron, we solved for the final velocity of the electron. Then using $D = 1/2 A T^2$ where $D$ is the length of the cathode ray tube, we solved for the time. Using this time, we plugged in the information into $MA = qvB$ to find the B field needed to move the electron into the "goal".

2. What did you learn in lecture and recitation this week?

I learned some additional properties about magnets and inducing a current in a wire from a changing B field.

How did you learn it?

By adding additional random energy, it is possible to break up the organization of molecules caused by a B field. By placing a wire in a changing B field, a current is induced through the wire in the same manner that a current through a wire induces a B field. Flux is the integral of the B field x dA and is measured in Webers. To demonstrate this, we took a metal ring and slid it down over a metal rod. A coil with current flowing through it, then created a strong B field upwards through the rod and up through the
metal ring. The increase in B field, made the metal ring create a B field to resist this change. The B fields then repelled each other and propelled the ring upward.

3. What questions remained unclear?

What is flux and what does it do? Is flux the relationship between area and strength of the B field? And does flux indicate the amount of current to be induced?

4. If you were the professor, what questions would you ask to determine if your students understood the material?

Have a uniform B field and place a ring of wire in the B field. Then solve for the flux.
## APPENDIX C

### NUMBERS OF CODE INDICATIONS EACH WEEK FOR 6 HIGH GAINERS AND 6 LOW GAINERS FROM 2000-2001

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A. Van Heuvelen, “Using interactive simulations to enhance conceptual development and problem solving skills,” in *The Changing Role of Physics Departments in Modern Universities: Proceedings of the International Conference on Undergraduate Physics*


